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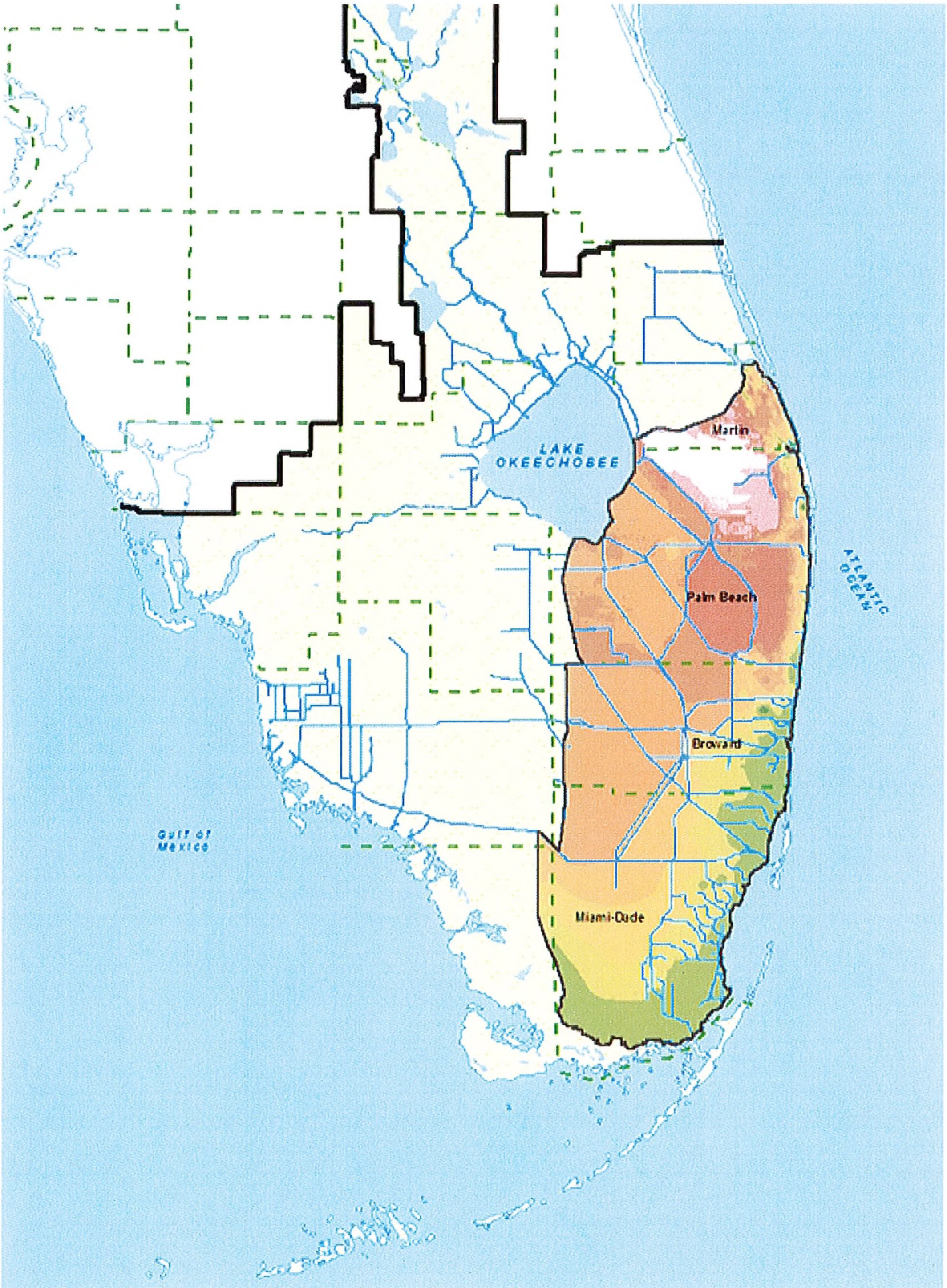
Lower East Coast Subregional MODFLOW Model Documentation



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March 2006

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Lower East Coast subRegional (LECsR) MODFLOW Model Documentation

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EXECUTIVE SUMMARY

For many years, water supply planning and restoration projects have used regional or high-resolution sub regional, numerical models for analysis in the LEC. The principal tool used by the SFWMD for the regional analysis of its water control system is the South Florida Water Management Model (SFWMM). The SFWMM simulates the groundwater system within its boundary using a vertically aggregated, single layer to emulate the composite effects of the nonhomogeneous, surficial aquifer. However, the grid cell size is quite large (2 miles by 2 miles) and is not well suited for evaluating sub regional scale projects. This model was originally developed by MacVicar and others (1984) and has undergone numerous revisions as more information about the surface water and groundwater system becomes available.

Several high-resolution, sub regional groundwater flow models were also developed to evaluate potential benefits and impacts of proposed changes to the water management system. Models developed most recently include the Martin County Groundwater Model, North Palm Beach Groundwater Model, South Palm Beach Groundwater Model, Broward Groundwater Model, North Miami-Dade Groundwater Model, and South Miami-Dade Groundwater Model. These models use the United States Geological Survey (USGS) modular three-dimensional finite difference groundwater flow model, commonly known as MODFLOW. These models have previously been used to support numerous projects in the Restudy, Florida State Senate Bills, the Water Preserve Feasibility Study, the Lower East Coast Water Supply Plan, permitting of the FEMA C-4 Impoundment, permitting and analysis of the G-160 structure, among others.

In order to simulate the majority of the LEC planning area, the sub regional models were modified, updated, and combined into one model, the Lower East Coast sub regional Model (LECsR). Several factors influenced the decision to develop the model, LECsR. First, the knowledge base relating to hydrology and hydrogeology of south Florida is growing continually, owing to extensive monitoring networks and cooperative efforts, such as the Restudy and CERP. Increased knowledge of the system has tied in with the development of several add-on packages to MODFLOW, which simulate complex system interactions involving water restrictions, wetland hydroperiods, and flow diversions. In conjunction with the system knowledge, advancements in computer technology have influenced the development, maintenance, and application of one, high-resolution model spanning a large area (approximately 7,500 square miles). Maintaining and applying one, large model, rather than six, county-specific models, promotes efficient use of human resources, as well as consistent methodology during model development.

The sediments composing the Surficial aquifer system and the Biscayne aquifer are primary marine carbonate and clastic sediments of Pleistocene to Miocene age. The model was discretized into three layers utilizing Chronostratigraphic correlation of the

sub-aerial exposure surfaces within these sediments resulting from the periodic submergence and emergence of the Floridan peninsula from fluctuations in sea level stands.

The LECsR encompasses approximately 7500 square miles. It ranges from C-44/Stuart to the north, the Atlantic Ocean on the east, Lake Okeechobee and the western edge of the Water Conservation Areas and the West, and Biscayne Bay/Florida Bay on the south. A grid spacing of 704 foot by 704 foot was chosen to match the SFWMD regional models which can be used to provide internal boundary conditions for future simulations. The model was calibrated over an extend period of 14 years from January 1986 through September of 1999 with daily time steps and stress periods. The model was primarily calibrated to observed heads with an overall mean error of 0.0 feet, a mean absolute error of 0.54 feet and root mean square error of 0.72 feet. The calibration results indicate a reasonable match between observed and measured water levels in most areas of the model domain. The model was verified from September, 1999 through December, 2000 and produced similar results to the calibration period. The budget from the model indicates that recharge to the aquifer is the primary inflow to the system with evapotranspiration and canal drainage as the primary outflows.

The model can provide an understanding of the movement of water in the study area. The model proved quite robust considering the long term daily calibration and verification periods in its overall performance during the simulation period. The calibration period included both a 1 in 100 year drought and a 1 in 100 year wet events and the model did not react adversely to these extreme events. The LECsR model conceptualization and discretization was designed at a subregional or basin level scale. The special variability of the input parameters is also best described at a similar scale. Therefore, the model should be used for regional to subregional or basin level projects and interpretation of the results should also be at that scale. In addition, the model does provide a reasonable estimate of drawdowns associated with wellfield withdrawals and the ground/surface water interactions within wetland systems.

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CHAPTER 1
Introduction

BACKGROUND

Development of the Lower East Coast Subregional (LECsR) Model was initiated by the South Florida Water Management District (SFWMD), Model Application Section of the Water Supply Department to support ongoing water supply management and ecosystem restoration efforts with computer modeling. This modeling project supports the development of several authorized activities including:

- Lower East Coast (LEC) Regional Water Supply Plan (Section 373.0361, F.S.),
- Minimum Flows and Levels (MFLs) for the Loxahatchee River, Biscayne aquifer and other watercourses (Section 373.042, F.S.),
- Core SFWMD projects for evaluating engineering designs, permitting and operational rules,
- Water Reservations (Section 373.223(4), F.S.),
- Several components in the Comprehensive Everglades Restoration Plan (CERP) (USACE and SFWMD 1999), and
- Acceler8 (Bush and Gutierrez 2004).

Water supply plans develop strategies (based on a 20-year future planning horizon) to meet future water demands of urban and agricultural uses, while meeting the needs of the environment by identifying historically used sources that will not be adequate to meet future demands and evaluating other source options to meet the deficit. Minimum flows and levels identify the groundwater levels in an aquifer and surface water levels and flows at which further withdrawals would significantly harm the resource. MFLs must be established for surface waters and aquifers within the boundaries of all water management districts, which are directed to use the best available data. Water reservations protect fish and wildlife or public health and safety while protecting existing legal uses of water by reserving water from consumptive uses in designated areas of concern. The Water Resources Development Act of 2000 (Public Law No. 106-541, of the 106th Congress) provides approval to restore the south Florida ecosystem in a plan called CERP, which consists of 60 components that include above- and under-ground water storage, preserve and treatment areas, decompartmentalization of natural areas, operational changes to improve ecology and water conservation benefits, and reuse of water. Acceler8 is an initiative by the State of Florida, SFWMD, and federal partners to

accelerate the completion of eight, identified projects from the CERP. By accelerating the completion of these projects, benefits from the Everglades restoration will be experienced sooner than originally scheduled. These projects require numerical tools that can quantify the availability of current water resources and in most cases, estimate or predict the demands on future water resources.

The study area focuses on the greater part of the Lower East Coast Planning Region, which covers roughly 10,500 square miles, and consists of a large freshwater lake, wetlands and estuaries, uplands, agricultural and urban areas, and coastal ecosystems lying within a highly managed system of canals, operational structures, levees, and retention ponds (**Figure 1**). This area continues to experience population growth and a subsequent increase in overall water demands, which must be balanced with the water needs of the environment.

PURPOSE AND SCOPE

The purpose of this project is to develop a numerical model capable of simulating the groundwater flow of the Surficial Aquifer System (SAS), wetland hydroperiods, water deliveries, canal-aquifer interaction, and general management of the water resources for the Lower East Coast of Florida. The model will be used as an interpretive and predictive tool and must be flexible enough to answer a wide range of questions.

The model will be used primarily to perform predictive simulations of proposed water resource projects and/or operational schemes. It will also be used as an interpretive tool for the SFWMD by identifying data gaps in aquifer characteristics, hydrogeologic, stratigraphic and hydrologic parameters, and producing water budgets and groundwater flow maps to better understand the surface/groundwater system. In addition, due to the extensive data collection and quality assurance and control efforts associated with model development, data sets can be used for a wide variety of purposes including populating various databases and providing information to the public according to Florida's Public Records Laws (Section 119.07, F.S.).

The model was developed to support several current and future projects in the LEC. The ability to evaluate water levels for water availability, cumulative wellfield impacts to natural areas or existing legal uses of water, water table increases that could potentially affect flood protection, and the frequency and severity of water shortages was considered when designing this numerical model. Water supply managers evaluate urban and agricultural water uses and must ensure current and future reasonable beneficial uses while protecting and restoring the environment and water resources. Due to these considerations, and to account for the complexities of the aquifer and drainage systems, the model must adequately represent horizontal and vertical aquifer heterogeneities and canal hydraulic properties.

Figure 1. Boundaries for the South Florida Water Management District Planning Regions.

Other considerations were made to accommodate ecosystem restoration goals and objectives. The ability to simulate hydropatterns in natural systems, water storage scenarios (e.g., siting a reservoir, delivering water to natural or urban areas as necessary), and impacts to adjacent water users was recognized when designing this model. In order to address these requirements, the model needed to take into account the vertical and horizontal flux components of the wetland-aquifer interaction, include a mechanism to manage and store water deliveries, quantify canal seepage from the aquifer, and represent partially or fully penetrating flow barriers.

Moreover, this report documents the development of a three-dimensional, numerical model, which simulates transient groundwater flow and the full hydrologic cycle in wetlands (i.e., integrated surface water-groundwater) in the LEC Planning Region. This is a technical document to help familiarize engineers, hydrogeologists and project stakeholders and the public with the model and its potential applications. It is not intended to serve as a user's manual for model applications.

With these objectives in mind, the scope of this document covers the development of the model in its entirety. This chapter (**Chapter 1**) has introduced the purpose and scope of this study, while referencing previous modeling studies that supported SFWMD goals. **Chapter 2** presents the development of the conceptual model. Available data is collected and assembled accordingly to define the hydrogeologic system. Simulating the flow system involves two aspects – code selection and model design - which are discussed in **Chapter 3**. **Chapter 4** details the processes of model calibration, sensitivity analysis and verification. Conclusions and recommendations with respect to model capabilities, limitations, and future improvements of this modeling study are presented in **Chapter 5**.

A standard protocol for model development requires completing the steps in **Chapters 1**, **2**, **3** and **4** (Anderson and Woessner 1992). The modeling protocol begins by establishing the purpose of the model. Having a clear idea of what questions need to be answered will help determine the magnitude and complexity of the model. Building a conceptual model is the next step. This step involves collecting data and assembling data into a meaningful representation of the system. At this stage, the modeling team should know the location of the system boundaries, the water budget components, and the flow system.

Selecting the mathematical and numerical models require that the governing equations are valid (for the processes described in the conceptual model) and that the computer code accurately solves those mathematical equations. Model design begins with the spatial discretization of the grid and also involves choosing the appropriate temporal discretization. This stage also includes setting initial parameter values for properties and system stresses, as well as defining initial and boundary conditions.

After the initial design of the model, the model will be executed numerous times with the intention of reproducing field (or measured) water levels and flow rates. This step is called model calibration and the model is considered to be calibrated when the

simulated and measured (or historical) water levels and flows meet the specified calibration criteria. A sensitivity analysis is conducted to quantify and show the effects of uncertainty in the calibrated model.

The last required step in the modeling protocol is model verification. A second set of field data is developed and the model is executed. If the model results meet the established calibration criteria, there will be greater confidence in the calibrated model.

PREVIOUS SUBREGIONAL MODEL DEVELOPMENT

For many years, water supply planning and restoration projects have used regional and/or high-resolution subregional numerical models for analysis in the LEC Planning Region. A regional model is defined herein as a numerical model with a low spatial resolution and large spatial extent. Typically, a regional model evaluates the system-wide water resources for planning and management of those resources. A subregional model is a numerical model with a high spatial resolution and moderate to large spatial extent. Subregional models can also be used for planning and management of regional water resources, though these models generally address county-wide or local concerns that a regional model is not designed to address.

The principal tool currently used by the SFWMD for the regional analysis of its water control system is the South Florida Water Management Model (SFWMM), which is considered a regional model (i.e., grid resolution of 2 miles by 2 miles with daily stresses). This model simulates structure operations and couples surface water and groundwater systems within its boundary, but has a coarse spatial discretization. Groundwater is represented using a vertically aggregated, single layer to emulate the composite effects of the nonhomogeneous, SAS. This model was originally developed and documented by MacVicar and others (1984) and has undergone numerous revisions (SFWMD 2005) as more information about the regional system has become available.

Several high-resolution (i.e., grid resolutions between 500 ft and 1320 ft with daily stresses), subregional groundwater flow models were developed to evaluate potential benefits and impacts of proposed changes to the water management system. The most recently developed groundwater models include those for Northern Palm Beach County (SFWMD 2001), South Palm Beach County (Nair *et al.* 2001), Broward County (Restrepo *et al.* 2001), North Miami-Dade County (Wilsnack *et al.* 2000), and South Miami-Dade County (Restrepo *et al.* 2001). These models use the U.S. Geological Survey (USGS) modular three-dimensional finite difference groundwater flow model, commonly known as MODFLOW (Harbaugh and McDonald 1996; McDonald and Harbaugh 1988). **Figure 2** depicts the boundaries of the SFWMM and subregional, county-specific models. Originally, the subregional models addressed county-level problems and the knowledge base was specific to each county and its water resources.

These previous subregional models utilized internal, surface water boundary conditions from the South Florida Water Management Model for predictive simulations

in the Lower East Coast Water Supply Plan (SFWMD 2000) and for the Comprehensive Everglades Restoration Plan (USACE and SFWMD 1999). Boundary conditions obtained from the regional model include canal stages and structure flows. The coupling of the regional and subregional models was necessary to evaluate water conditions in the urban areas, including urban wetland systems, at a finer resolution. Due to the large number of wellfields close to natural areas and the saltwater interface near the coast, this finer resolution was required due to the inability of the regional model to adequately predict the cone of influence from the wellfield withdrawals. Conversely, the subregional models did not simulate the operation of the Central and Southern Florida Project (USACE and SFWMD 1999) including the operations of Lake Okeechobee (see **Figure 1**). For the urban wetland systems, which are generally much smaller than the regional model cells, the subregional models helped address potential impacts as well as evaluate improved hydropatterns due to the changes in water control structure operations.

In order to simulate the majority of the LEC Planning Region, the subregional models were modified, updated, and combined into one model, the Lower East Coast subRegional Model (LECsR). Several factors influenced the decision to develop the LECsR Model. First, the knowledge base relating to hydrology and hydrogeology of south Florida is growing continually, owing to extensive monitoring networks, cooperative efforts (e.g., Comprehensive Everglades Restoration Plan [USACE and SFWMD 1999]), and research partnerships with other agencies (e.g., FAU and USGS). With respect to the groundwater models, increased knowledge of the system has tied in with the development of several add-on packages to MODFLOW, which simulate complex system interactions involving water restrictions, wetland hydroperiods, overland flow and surface water-groundwater interaction in wetland systems and canals, and water deliveries (or diversions). In conjunction with the system knowledge, advancements in computer technology (see **Chapter 3**) have influenced the development, maintenance, and application of one, high-resolution model spanning a large area (approximately 7,500 square miles). Maintaining and applying one large model (LECsR), rather than five county-specific models, promotes efficient use of human and computer resources as well as consistent methodology during model development and application. This model will be applied for both regional and basin-scale projects.

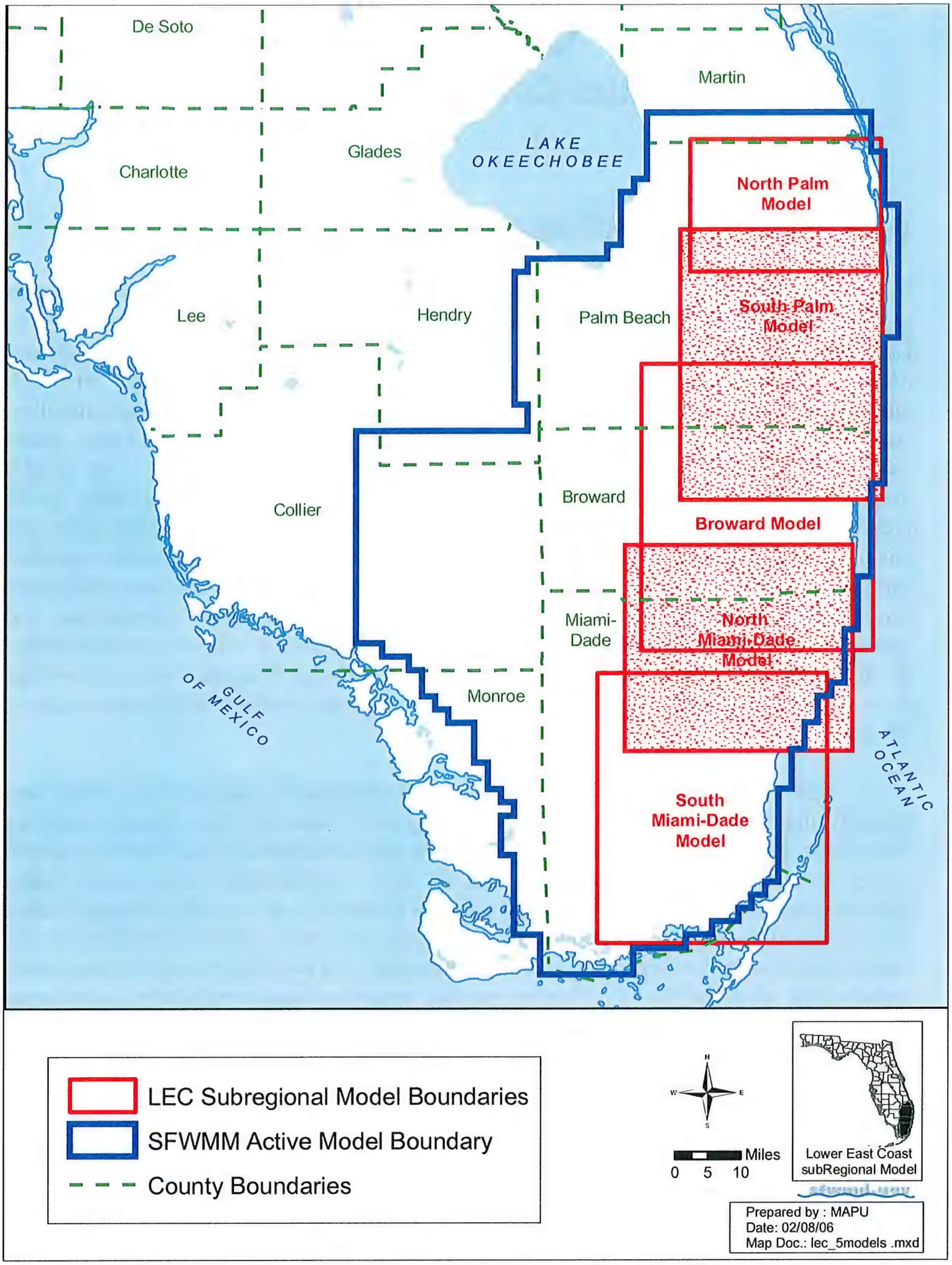


Figure 2. Locations of the Boundaries for the LEC County-Specific Subregional Models and the South Florida Water Management Model.

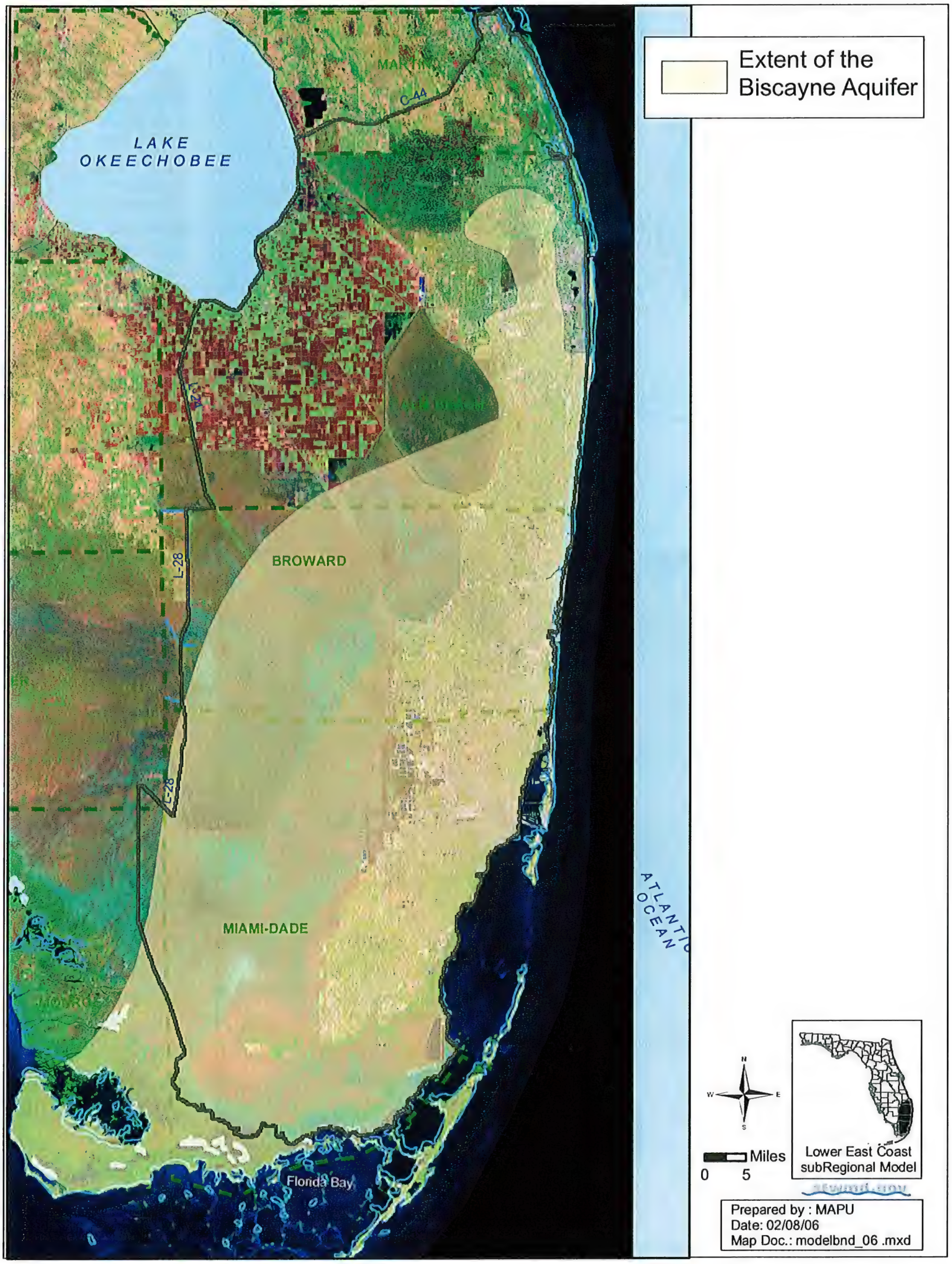
CHAPTER 2
Model Conceptualization

DESCRIPTION OF THE STUDY AREA

The study area for this report includes the Lower East Coast of Florida as shown in **Figure 3**. This area encompasses southern Martin County, the majority of Palm Beach, Broward, and Miami-Dade Counties, and eastern portions of Collier and mainland Monroe Counties; however, the focus of the study area lies within Palm Beach, Broward, and Miami-Dade Counties. This area includes the urbanized coastal communities, Everglades Agricultural Area (EAA), Stormwater Treatment Areas (STAs), Water Conservation Areas (WCAs) and Everglades National Park (ENP). STAs cover 47,000 acres of large constructed wetlands which are designed to reduce phosphorus levels entering the Everglades to 50 parts per billion (ppb). WCAs are made up of saw grass and island hammocks, which are divided into five, enclosed compartments and are regulated through a series of pumps, weirs and canals. Everglades National Park consists of preserved, subtropical wetlands with temperate and tropical plant communities and marine and estuarine environments. The Florida Keys and barrier islands are not included in the study area due to the limited and thin freshwater lens that exist on several Keys and islands, which are not connected to the primary Surficial aquifer resources of the area.

The study area was further refined and delineated using surface water and groundwater boundaries in south Florida (**Figures 3 and 4**). The eastern boundary coincides with the Atlantic Ocean and follows the brackish Intracoastal Waterway which serves as a stable physical boundary. The St. Lucie Canal (C-44) from the St. Lucie Estuary west to Lake Okeechobee is the northern boundary and is a large, managed canal that is part of the regional, surface water management system. Lake Okeechobee, in the northwestern corner of the study area, is a managed lake and the primary surface water supplier for southeast Florida. Western surface water boundaries include primary water management district canals (i.e., from north to south, L-24 and L-28) until reaching Everglades National Park. The southern model boundary is defined by water levels in ENP near the groundwater divide and along Florida Bay.

The Surficial Aquifer System, which includes the Biscayne aquifer, forms a physical boundary. The extent of the Biscayne aquifer forms the primary physical, aquifer boundary in the majority of the study area (**Figure 3**). The SAS is composed of both the Water Table and Biscayne aquifers, which lies within, but also extend beyond the study area boundaries.



Surface Water and Groundwater Boundaries that Define the Study Area.

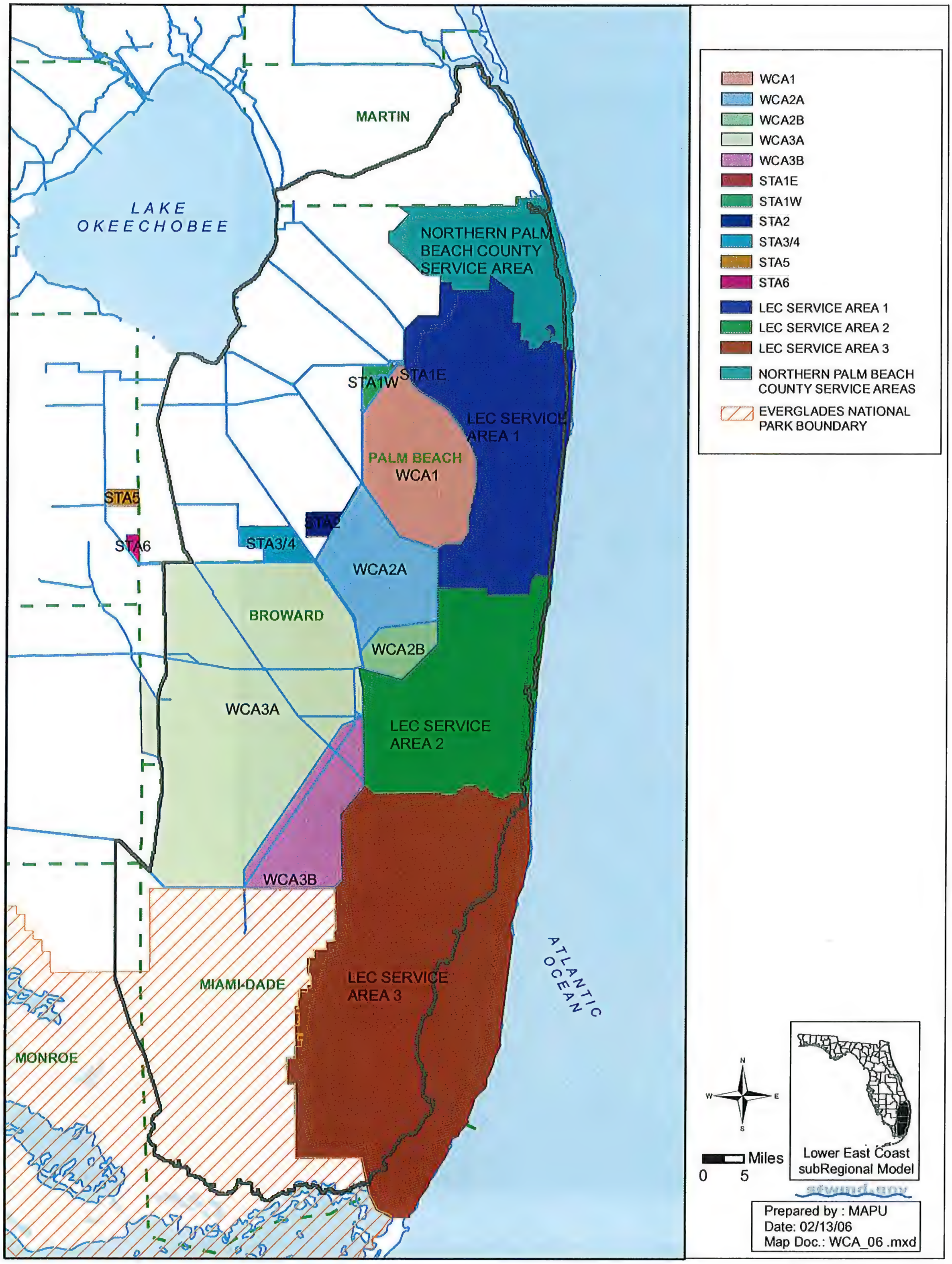


Figure 3. Natural and Urban System Boundaries.

PHYSIOGRAPHIC REGIONS AND TOPOGRAPHY

White (1970) delineated ten distinct physiographic regions in Florida. Five of these regions are intersected by the study area and shown in **Figure 5**. South Florida is unique for the east coast of the United States in that the land extends to the edge of the Continental Shelf as a result of rapid deposition of marine limestones during high sea level stands. Due to the low relief in Florida, White (1970) used a combination of natural features to develop the regions. The primary regions include the Everglades in the west, the Atlantic Coastal Ridge along the Atlantic coastline, and the Eastern Valley to the north. The Everglades is a broad low area in the center of South Florida, flanked by relatively higher lands to the east, west and north. It stretches from Lake Okeechobee southward to Florida Bay. The Everglades soils are generally peat overlying limestone with elevations ranging from sea level to + 12 feet, National Geodetic Vertical Datum of 1929 (NGVD). The Atlantic Coastal Ridge is located on the east adjacent to the Atlantic Ocean and is characterized by a series of beach ridge and dunes deposits laid down during previous high sea level stands. Elevations along the Atlantic Coastal Ridge range from sea level to over + 30 feet NGVD but generally are closer to +15 to + 20 feet NGVD. The northern part of the study area is situated in the Eastern Valley. This area has slightly higher elevations but it contains poorly drained isolated wetlands unlike the Everglades with its continuous wetlands in areas where it has not been developed. Smaller regions outside the study area include the Southern Slope, the Gulf Coastal Lowlands, the Florida Bay Mangrove Islands, the High Coral Keys, the Reticulate Coast Swamps, the Green Ridge and the Osceola Plain (**Figure 5**). Except for the coastal or beach ridges, the study area is relatively flat with a gradual reduction in elevation southward.

Topographic relief and the nature of surface water features affect the distribution of recharge and discharge within the study area. The Lower East Coast of Florida has low elevation, typically less than + 25 feet above sea level. The bottom of Lake Okeechobee is approximately at sea level with the water level in the lake ranging from + 11 to + 18 ft NGVD. The land immediately surrounding the lake has an elevation of about + 20 to +25 ft NGVD.

The topographic data was collected from a number of sources, listed in **Table 1**, including Light Detection and Ranging (LIDAR) data for the coastal areas of the model, the USGS High-Accuracy Elevation Data, as well as data from several other Digital Elevation Models developed for smaller regions of the study area (Hinton 2004), as illustrated in **Figure 6**. The USGS High Accuracy Elevation Data was used in Everglades National Park and Water Conservation Area 1. This data was collected on approximate 50 foot centers. Data for the Everglades Agricultural Area was collected using transects on 500 foot centers. In North Palm Beach County, a 5 foot Digital Elevation Model was developed from data collected using LIDAR. A digital elevation model was also developed using LIDAR for coastal Miami Dade County on 25 foot intervals. The remaining areas used small high resolution studies to fill small gaps or the USGS 24,000 Quad points which consist of various elevations and benchmarks assembled by the

USGS. LIDAR data was also used along the coast of Broward County and Martin County. If not already converted, all topography was converted to NGVD.

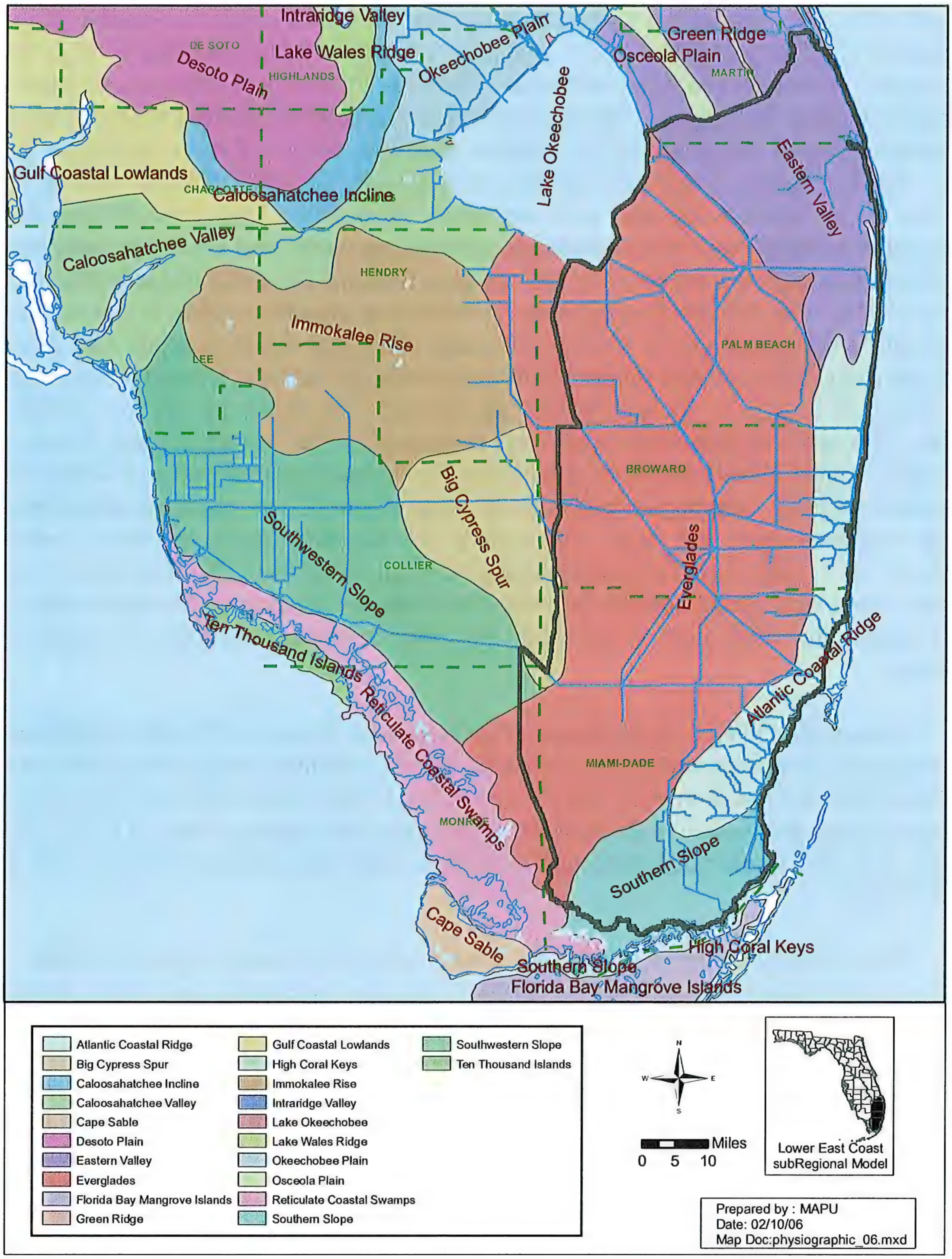


Figure 4. Physiographic Regions in the Lower East Coast Subregional Model (Modified from Florida Department of Environmental Protection).

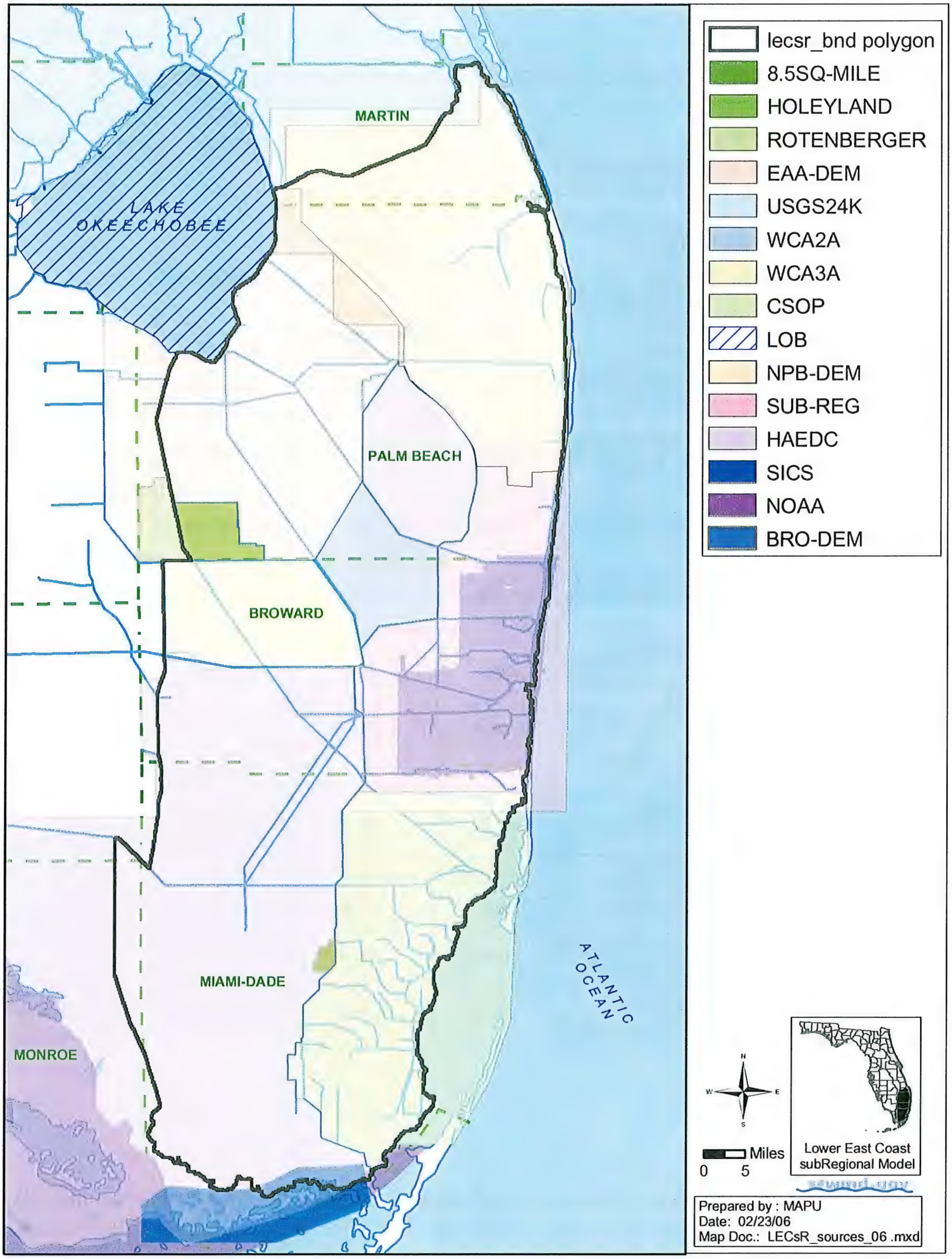


Figure 5. Data Sources Used to Develop The Topography for the Lower East Coast Subregional Model.

Table 1. Description of Sources Used to Develop the Topography.

Abbreviation	Name	Publication Date	Resolution	Vertical Accuracy	Original Vertical Datum
8.5SQ-MILE	1986 AeroMetric Corporation Survey of the 8.5 Square Mile Area	1986	300 ft	+/-4 in	NGVD29
HOLEYLAND	1992 Florida Game and Fish Commission Survey of Holeyland Wildlife Management Area	1992	.5-minute latitude/longitude grid	unreported	NGVD29
ROTENBERGER	1992 Florida Game and Fish Commission Survey of Rotenberger Wildlife Management Area	1992	.5-minute latitude/longitude grid	unreported	NGVD29
EAA-DEM	Everglades Agricultural Area Digital Elevation Model	2003	500 ft	unreported	NGVD29
USGS24K	U.S. Geological Survey 24K Quad Points (Topography Five Foot USGS 24k Points)	varies	varies	+/-2.5 ft	NGVD29
WCA2A	1992-3 Keith and Schnars Survey of Water Conservation Area 2A	1993	n/a	0.0003-0.0329 m	NAVD88
WCA3A	1999 EarthData International Survey of Water Conservation Area 3A	1999	5 m	+/-15 cm	NAVD88
CSOP	Combined Structure and Operational Plan for MWD and C-111 LIDAR Surveys Digital Elevation Model	2003	25 ft	unreported	NAVD88
LOB	Lake Okeechobee Bathymetry	unreported	unreported	unreported	NGVD29
NPB-DEM	North Palm Beach Digital Elevation Model	2004	5 ft	unreported	NGVD29/NAVD88
SUB-REG	SFWMD Subregional Groundwater Modeling Topography	varies	500 ft	unreported	NGVD29
HAEDC	USGS High Accuracy Evaluation Data Collection	1998-2004	400 m	+/-15 cm	NAVD88
BRO-DEM	Broward County LIDAR	2002	100 ft	+/-0.7 ft	NAVD88
SICS	USGS Southern Inland Coastal Systems Model Topography	1999	305 m	unreported	NAVD88
NOAA	NOAA Soundings from Everglades National Park Staff	varies	varies	unreported	MLLW, NGVD29

CLIMATE

The study area has a tropical to subtropical climate (Pendleton, Dollar and Law 1976). The summers are warm and relatively wet with mild, relatively dry winters. Temperatures are moderated by the close proximity of the Gulf Stream, which is located just off the south Florida coastline. The Gulf Stream originates in the Gulf of Mexico and flows around the tip of Florida, heading north into the northeastern Atlantic Ocean. Maximum temperatures rarely exceed 100 degrees Fahrenheit (F) and minimum

temperatures are rarely below freezing. The maximum humidity occurs by dawn while the minimum humidity usually occurs in the afternoon. The relative humidity in Florida generally exceeds 50 percent all year.

Data for rainfall and temperature were collected from the National Oceanic and Atmospheric Administration (NOAA) stations (**Figure 7**) and from the extensive SFWMD data base DBHYDRO. Rainfall stations were selected based on period of record, data quality, and spatial distribution. Stations with a long-term record were given preference. Published data from NOAA was preferred due to quality control. Twenty-six rainfall stations were selected for the study area. Similar criteria were used for selecting temperature stations which are used to determine reference evapotranspiration [ET] (SFWMD 2005). Unfortunately, long-term weather data are scarce in south Florida; most stations do not collect data for all the parameters required for a robust calculation of actual ET.

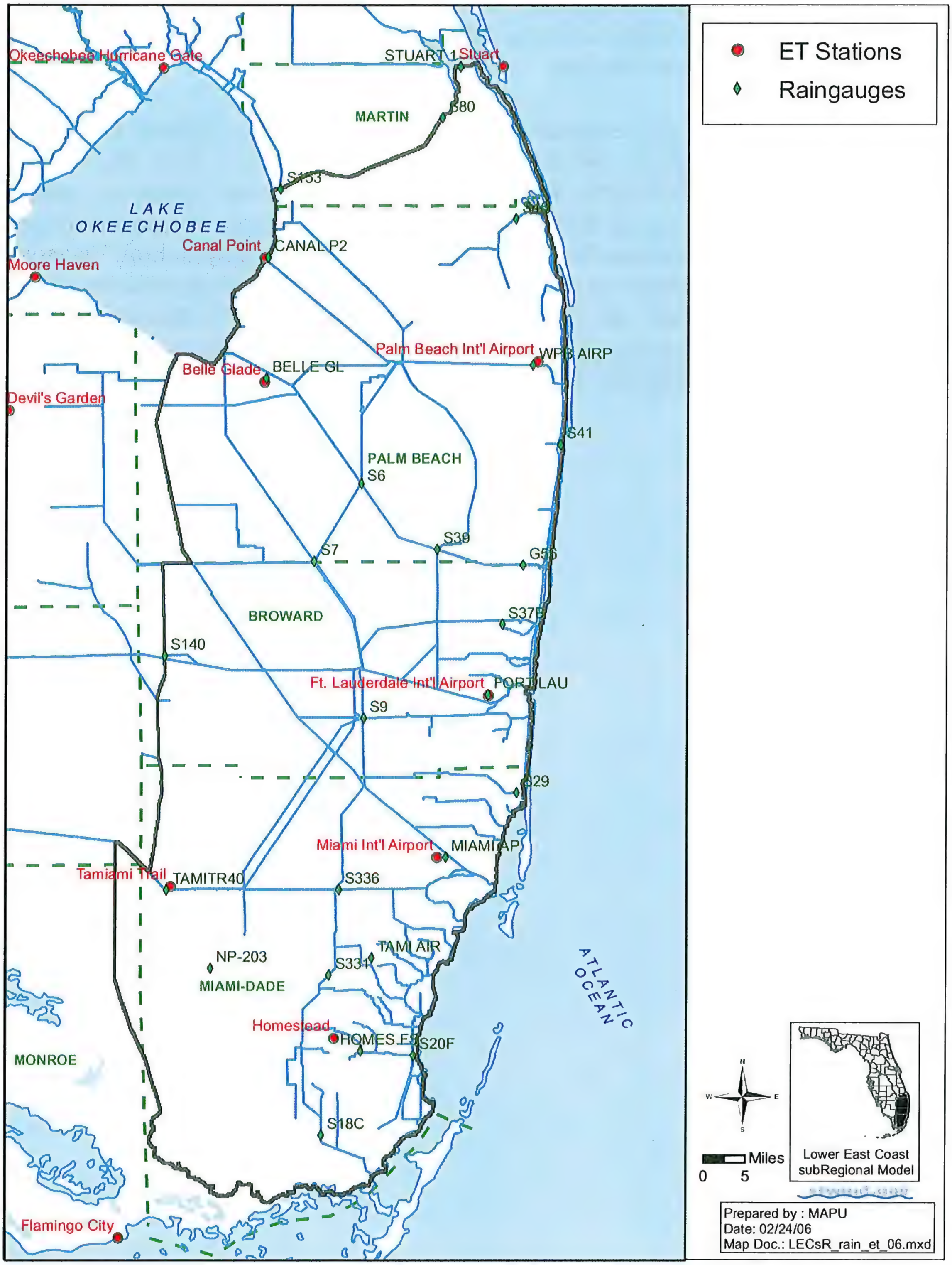


Figure 6. Locations of Rainfall and Temperature Stations. Temperature Stations are used to Develop Reference ET.

Rainfall

Rainfall represents the largest input of water into the hydrologic system. The average annual rainfall throughout the study area is 54 inches (**Figure 7**). The annual variation is high. Historically, at the West Palm Beach Airport, the wettest year on record is 1947 with 108 inches and the driest year is 1954 with 37 inches recorded. Over the last twenty years, the wettest year, 1994 had 86 inches but the driest year, 1989 had only 39 inches. Due to these extremes in annual rainfall, the region periodically undergoes flooding and prolonged drought.

Rainfall was summarized based on twenty-six rainfall stations over the years, 1965-2000. Rainfall, on an average annual basis is relatively consistent throughout south Florida; however, annual rainfall tends to generally decrease inland. Separate microclimates develop mainly associated with the tropical sea-breeze front, Everglades System, and Lake Okeechobee. Using 1992 as a typical year, average annual rainfall for coastal stations is 62 inches, which is above the annual rainfall of 58 inches for the inland stations.

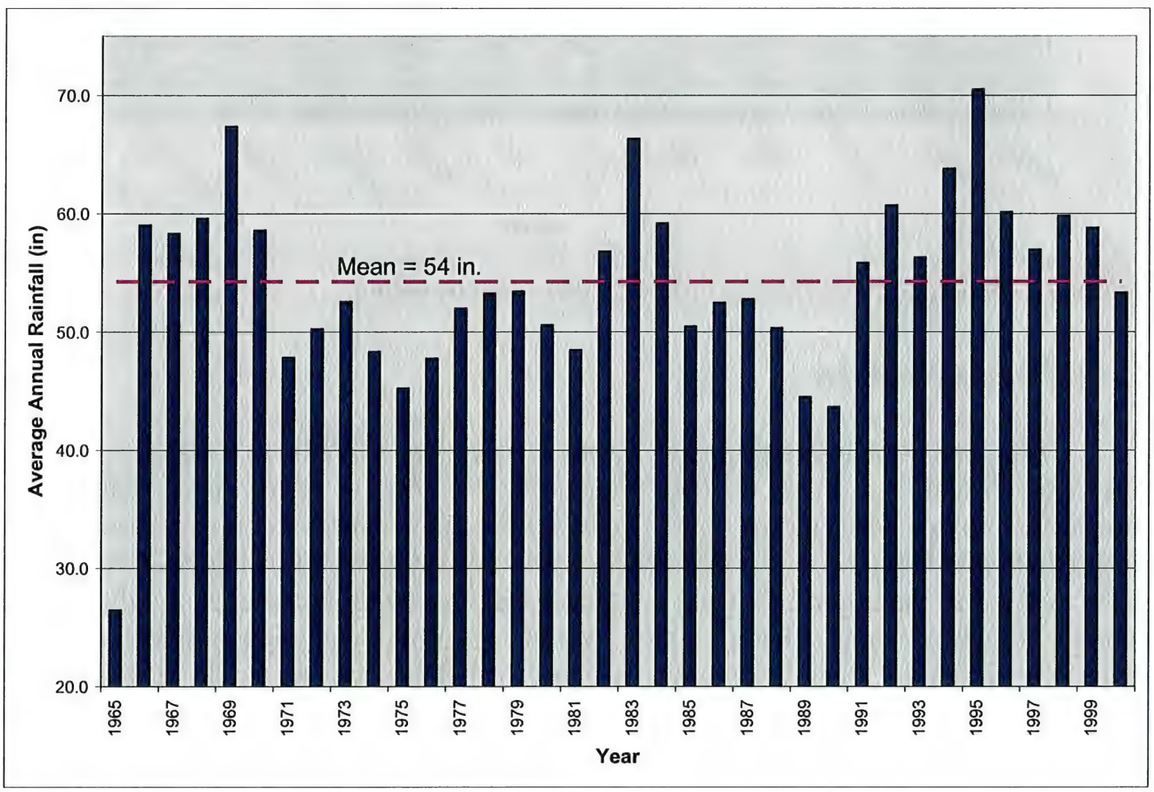


Figure 7. Average Annual Rainfall (in) from 1965 -2000.

On a daily or even weekly basis, the distribution of rainfall can vary dramatically across the region. This is especially true during the summer months when warming tends to create scattered afternoon thunderstorms referred to as convective rainfall.

Approximately 75 percent of the rain falls during the wet season (May through October) (**Figure 9**). Rainfall is provided by thunderstorms, tropical storms, and hurricanes in the summertime and passing cold fronts during the winter months.

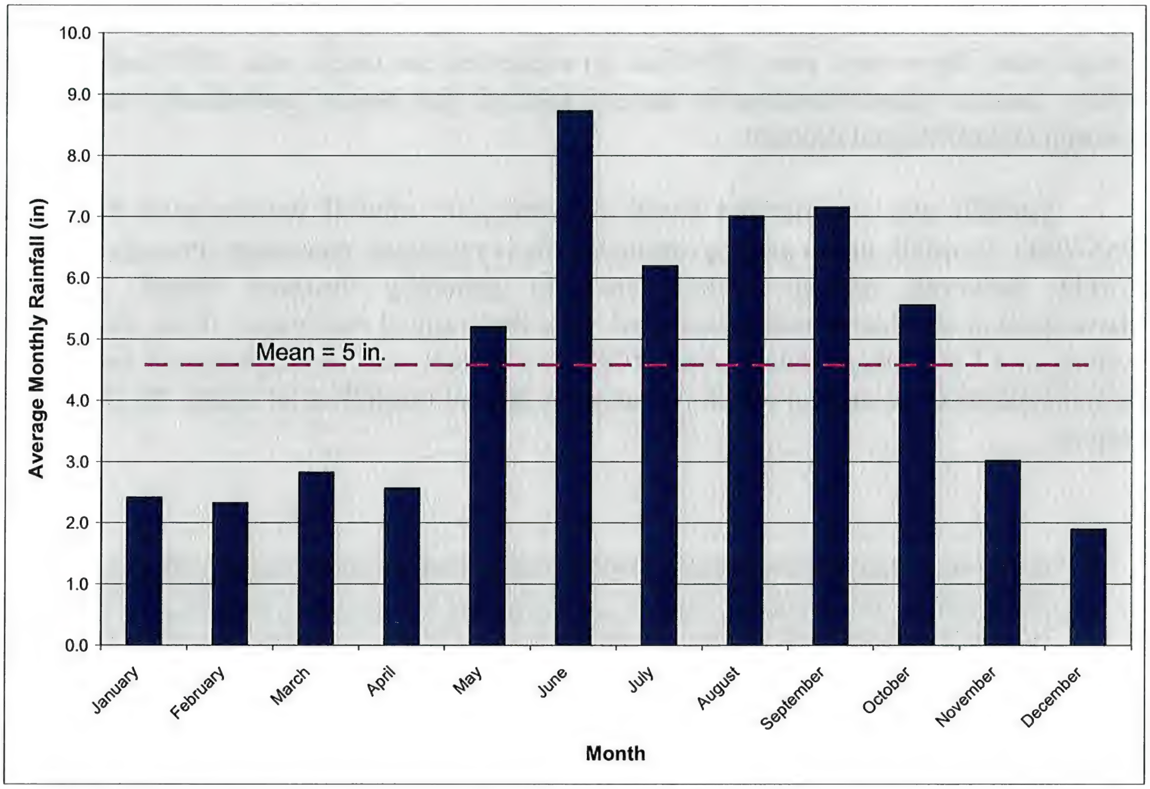


Figure 8. Average Annual Rainfall (in) from 1965 -2000 by Month.

Evapotranspiration

Temperature stations (**Figure 7**) were used by the SFWMD to develop a regional reference ET data set based on the Simple Method (Abtew 1996). This method was selected to provide estimates of long-term historical (1965-2000) wet marsh potential ET for predictive simulations (SFWMD 2005) and will be discussed in Chapter 3. Reference ET is defined as the rate of ET from a hypothetical crop with an assumed height, a fixed canopy resistance, and albedo, which would resemble evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and not short of water (FAO 1990). The reference crop should be taken as a hypothetical crop with fixed parameters and resistance coefficients. These crop coefficients are complex empirical factors derived from experimental data and encompass all characteristics of the crop which differ from those of the reference crop. These coefficients quantify how soil and crop conditions affect actual ET.

Evapotranspiration represents the largest water loss from the system and was summarized based on seventeen NOAA stations over the years, 1965-2000. In general,

reference evapotranspiration is on the order of 55 in to 59 inches per year (**Figure 10**) for a wet marsh crop. In south Florida, it is recommended that grass be used as the reference crop, since previous studies have been conducted utilizing grass as a reference crop. Consequently, all the crop coefficients are based on grass. However, to ensure consistency between the regional and subregional modeling efforts, this study will use the data set that applies the wet marsh crop (herein referred to as reference crop) developed and used by the regional models.

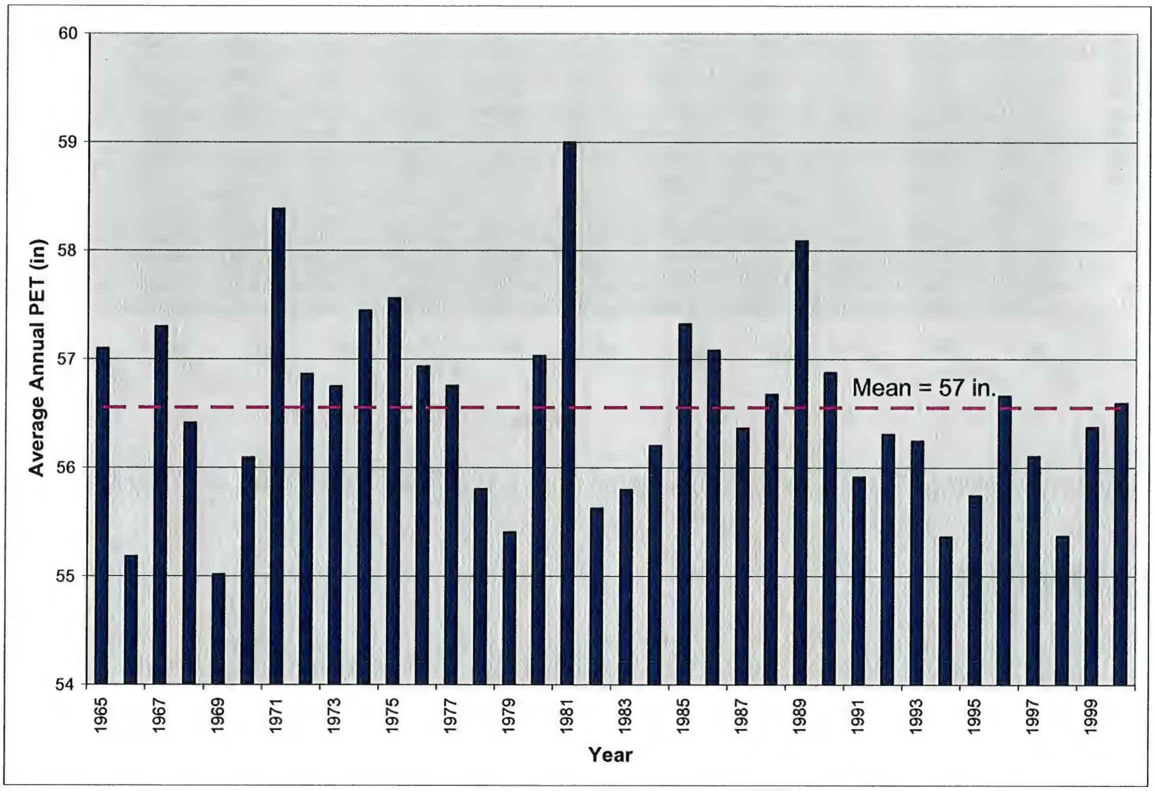


Figure 9. Average Annual Evapotranspiration (in) for Wet Marsh from 1965 -2000.

Actual ET depends on the availability of water to the crop and most often is less than the potential ET which has no constraints on available water. Although not as varied as rainfall, actual evapotranspiration rates in south Florida can be greater than 40 in/yr and can approach and even exceed rainfall rates during drought events (USGS 1996).

The monthly distribution of reference ET (**Figure 11**) follows a bell-shaped curve. Over the thirty-six year period of record, the month with maximum ET rates is May. Reference ET is lowest during the month of December. In general, the distribution of reference ET follows the solar radiation curve.

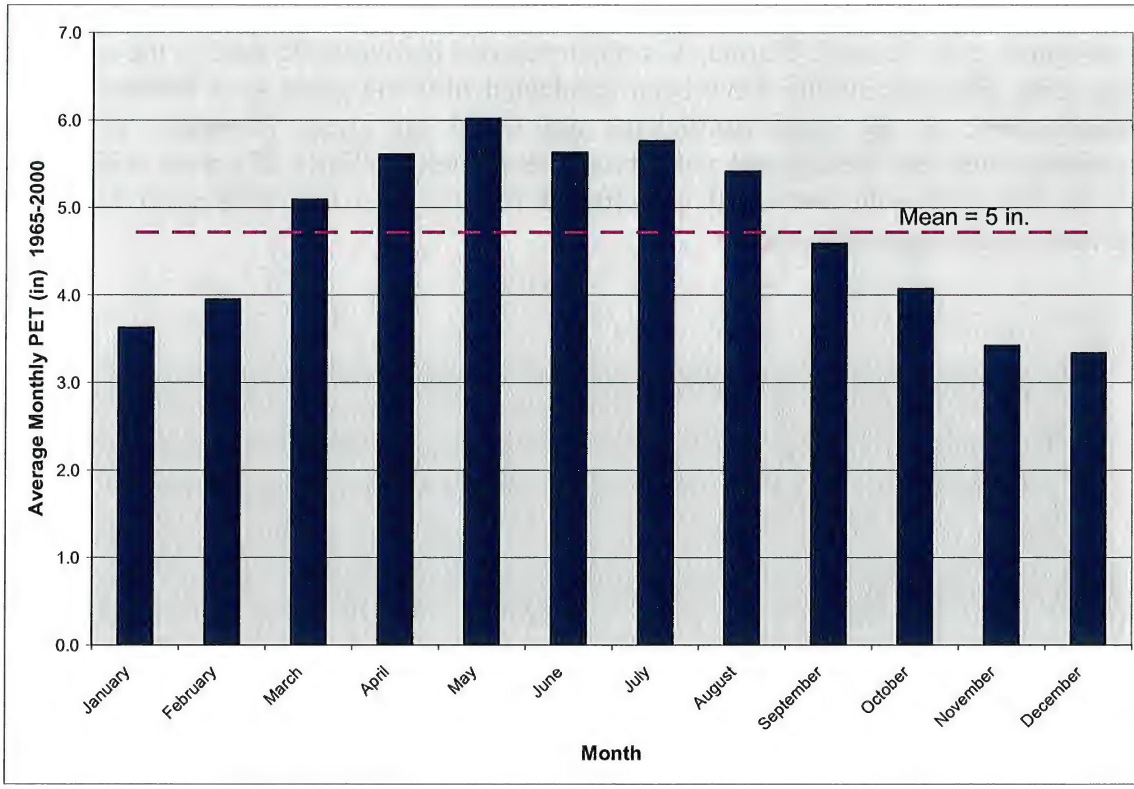


Figure 10. Average Annual Evapotranspiration (in) for Wet Marsh from 1965 -2000 by Month.

LAND USE

At the time of data collection, available land use and land cover data included 1988, 1995, 2000, and future data sets. The 1988 land use data were produced by photo interpretation of color infrared photography from the late 1980's and the accuracy of parameters has not been assessed. The 1995 land use data is a composite of vegetation types from a variety of sources and was linked to crosswalk tables that associate land use codes with the vegetation. The 2000 and future land use analysis used photo interpretation and Palm Beach, Broward, and Miami-Dade Counties' comprehensive water management plans to estimate the developable areas.

Land use was summarized herein using 1995 data. Land use classification includes several levels which give details about the type of use. **Figure 12** shows a partially aggregated level 3 classification (see **Table 2**). Wetlands cover half of the area and include large, expansive systems like the Everglades. Northern Palm Beach County contains several wetlands including those in Jonathan Dickinson State Park, Palmar, Corbett Wildlife Management Area, and Loxahatchee Slough. The second largest land use consists of urban and built up areas. The majority of these areas are generally within the boundaries of the LEC Service Areas; however, there are urbanized areas in the Lake Okeechobee Service Area. The largest percent of agriculture occurs in the EAA and is made up of mostly sugarcane.

Table 2. Percent of Total Area by Land Use Types in the Study Area.

Land Use Type	Acres	Percent
Wetlands	1608136	49
Water	68897	2
Urban and Built Up	618578	19
Transportation and Communications	82296	3
Barren Land	22132	1
Sugar Cane	429486	13
Agriculture Crops	91811	3
Other Agriculture	96416	3
Improved Pasture	38225	1
Unimproved Pasture	22718	1
Upland Non-Forested	8475	0
Upland Forest	198490	6

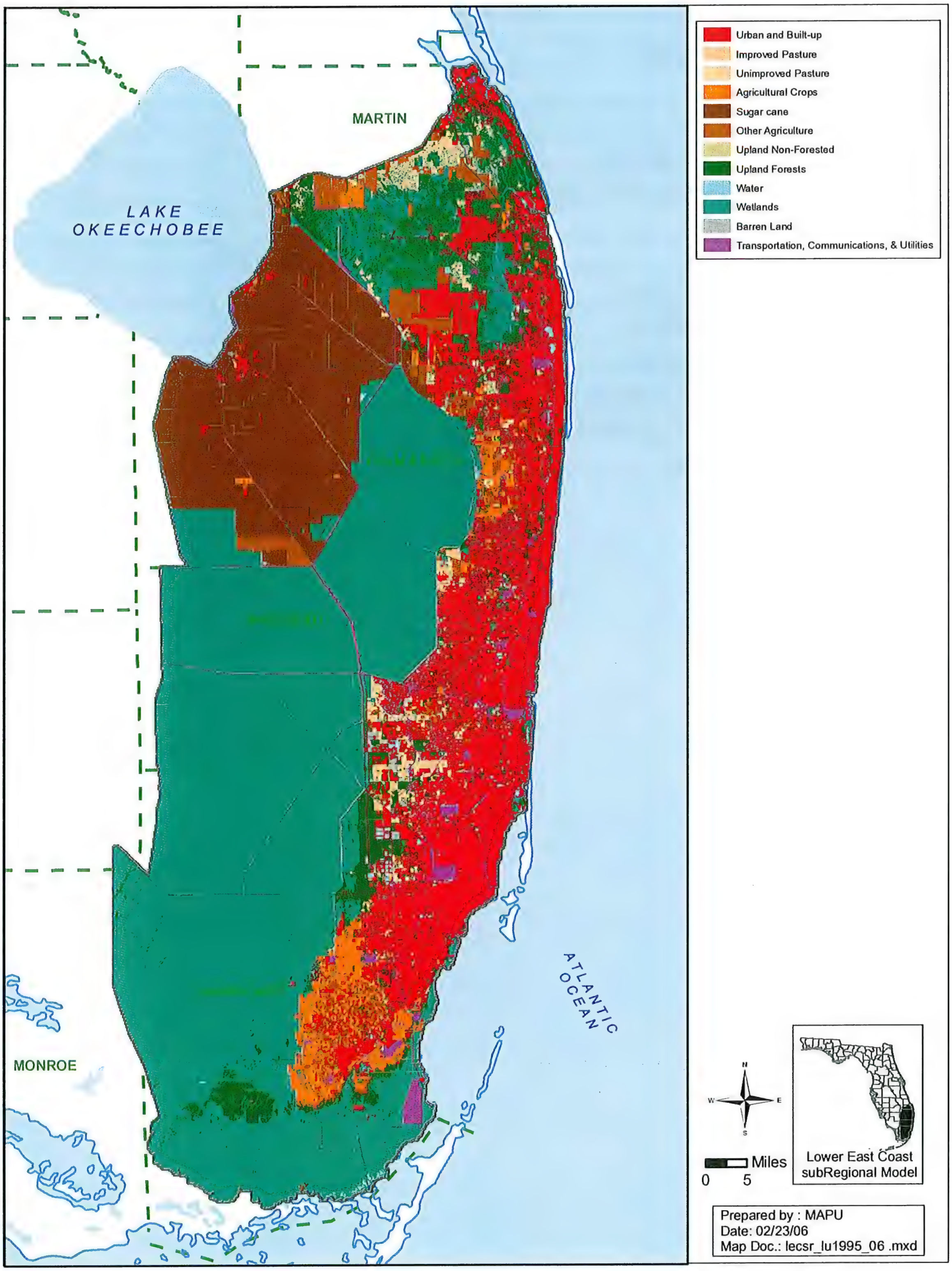


Figure 11. 1995 Land Use / Land Cover.

SURFACE WATER CHARACTERISTICS

Surface waters within the model area include Lake Okeechobee, numerous smaller lakes, retention ponds, limestone mining pits, a large wetland ecosystem (Everglades), numerous smaller wetland systems, the Wild and Scenic Loxahatchee River and its tributaries, numerous canals, coastal estuaries including Lake Worth Lagoon, Biscayne Bay and Florida Bay, and the Atlantic Ocean.

Surface Water Management Systems

There are three types of canal systems (or networks) – primary, secondary, and tertiary - in the SFWMD. Primary canals consist of canals and/or natural water courses providing final conveyance of overall drainage basin flows to the ocean or major inland water bodies. These canals are managed and operated by the SFWMD and, in certain cases, the U.S. Army Corps of Engineers (USACE). Secondary canals (e.g., drainage and water control district canals) are generally designed to control surface and groundwater elevations and maintain the quantity and quality of developed area runoff at pre-development levels. These canals typically discharge into the primary canal system or other natural waterways. Tertiary canals include swales, ditches, and retention ponds and are designed to remove stormwater in areas that are subject to inundation or provide irrigation to agricultural operations.

Water management in south Florida is controlled by the Central and Southern Florida Project originally constructed by USACE and maintained and mainly managed by the SFWMD. The project is divided into four regions which are hydrologically interconnected and include: 1) the Kissimmee River – Istokpoga Basin; 2) Lake Okeechobee and the Everglades Agricultural Area; 3) the Water Conservation Areas and Everglades National Park and 4) the East Coast Canals (USACE 1999). The Kissimmee River–Istokpoga Basin lies north of Lake Okeechobee and provides inflow to Lake Okeechobee; however, this basin lies outside the model area so a detailed discussion is not included.

Lake Okeechobee and the Everglades Agricultural Area

Lake Okeechobee is the largest freshwater lake in the State of Florida, and is one of the largest freshwater lakes in the United States. It is regulated to meet numerous uses including protection of fish and wildlife, flood control for surrounding agricultural and urban lands, water supply for the Everglades Agricultural Area, the environment and the coastal users, protection of the dikes from hurricane damage, minimum flows and levels demands from coastal estuaries and environmental systems, protection of coastal aquifers from salt water intrusion, recreational users, and waterway navigation across the lake.

Lake Okeechobee is regulated through a series of pumps and canals and is surrounded by approximately 1,000 miles of levees which range in height from approximately + 32 ft NGVD to + 45 ft NGVD. These pumps and canals maintain stages

in Lake Okeechobee within a seasonally changing band of high and low levels. Water levels in the lake are drawn down at the beginning of June to prepare for the hurricane and wet seasons. The target for this date is + 13.5 ft NGVD. Releases are made if the water level is higher than + 13.5 ft NGVD. Water levels lower than + 10.5 ft NGVD will trigger water restrictions from the lake. Releases are designed to protect the levees during a hurricane from wind-driven waves and tides, and also increases flood control for lands which discharge into the lake. Starting in October, water levels in the lake are allowed to rise to provide increased storage for water supply demands from users during the dry season. Releases will be made if water levels exceed the target of +15.5 ft NGVD. Water levels lower than +13.0 ft NGVD will trigger water restrictions from the lake during this time.

Demands on Lake Okeechobee to supply water come from a variety of sources and occur at any time of year but demands are highest during the dry season. The Everglades Agricultural Area located to the east and south of the lake is a large agricultural area which relies on the lake almost exclusively for its source of water. The communities that surround the lake also rely on the lake for public water supply; however, several of these communities are looking to groundwater from the Floridan aquifer system to meet their future demands. In addition, coastal canals are maintained with lake water, when other sources are depleted, to prevent saltwater intrusion, provide water to coastal agricultural operations and recharge coastal wellfields and lake systems. The lake also supplies water to environmental features, when local supplies are depleted, including Everglades National Park and coastal estuaries.

The Water Conservation Areas and Everglades National Park

The Water Conservation Areas are a vast expanse of saw grass and island hammocks which are divided into five compartments which are surrounded by levees with the exception of a small gap on the west side of Water Conservation Area 3A (see **Figure** 4). The southernmost compartment, Water Conservation Area 3A, is adjacent to the Everglades National Park, which is the only subtropical National Park in the United States. Similar to Lake Okeechobee, the Water Conservation Areas are regulated to meet numerous uses including protection of fish and wildlife, water supply for the Everglades National Park, water supply for coastal users and wellfields, protection of coastal aquifers from saltwater intrusion and recreational uses.

The Water Conservation Areas are regulated through a series of pumps, weirs and canals. These pumps and canals maintain stages in the Water Conservation Areas within a seasonally changing band of high and low levels. Water levels are drawn down at the beginning of June, which is the start of the wet season. During the fall, water levels are allowed to rise to provide increased storage for water supply demands from users during the dry season. Inflows to the WCAs are from local rainfall and runoff from the Everglades Agricultural Area to the north which is starting to be filtered (to remove nutrients) through several storm water treatment systems. During times of extreme drought, when the WCAs are below there minimum level, water is brought into the

WCAs from Lake Okeechobee, if available, and delivered to Everglades National Park or the coastal users.

East Coast Canals

The East Coast Canals are a series of canals which stretch approximately 170 miles from St. Lucie County to the north, southward through Martin, Palm Beach, Broward and Miami Dade Counties ending at Florida Bay. This area consists of numerous canals, spillways, structures, culverts and pump stations. Water levels are maintained in the canals at specific levels to provide water supply and improve flood protection for coastal urban and agricultural interests, but are also controlled at high enough levels to stabilize the saltwater interface in the Surficial and Biscayne aquifers. During times of drought, water is brought into these canals from either the Water Conservation Areas or Lake Okeechobee to maintain the minimum levels, recharge local wellfields and irrigate landscaping and agricultural operations by moving water from the primary to the secondary canal systems.

The East Coast Canals tie into secondary canal systems. The secondary canal systems were not constructed as part of the Central and Southern Florida Project. Runoff from the urban areas is discharged through the secondary canals into the primary canals, which ultimately release the water to tide for flood protection. During the dry season, or in some cases, during periods of low rainfall, secondary canal systems pump water from the WCAs or East Coast Canals to maintain minimum levels. Other times, secondary systems close off the connection to the East Coast Canals to avoid free canal flow from the secondary canals.

Figure 13 shows the spatial variation in the primary and secondary canal systems due to different rules of operations across the study area. The control levels in the secondary canal system are primarily based on dry and wet season criteria and have a large impact on the Surficial Aquifer System by trying to maintain the control levels. The control levels for these secondary canal systems are determined by the local entity operating the system. Therefore, there are several hundred different control elevations for these canal systems. In general, the control elevations decrease from the north to the south and towards the coast.

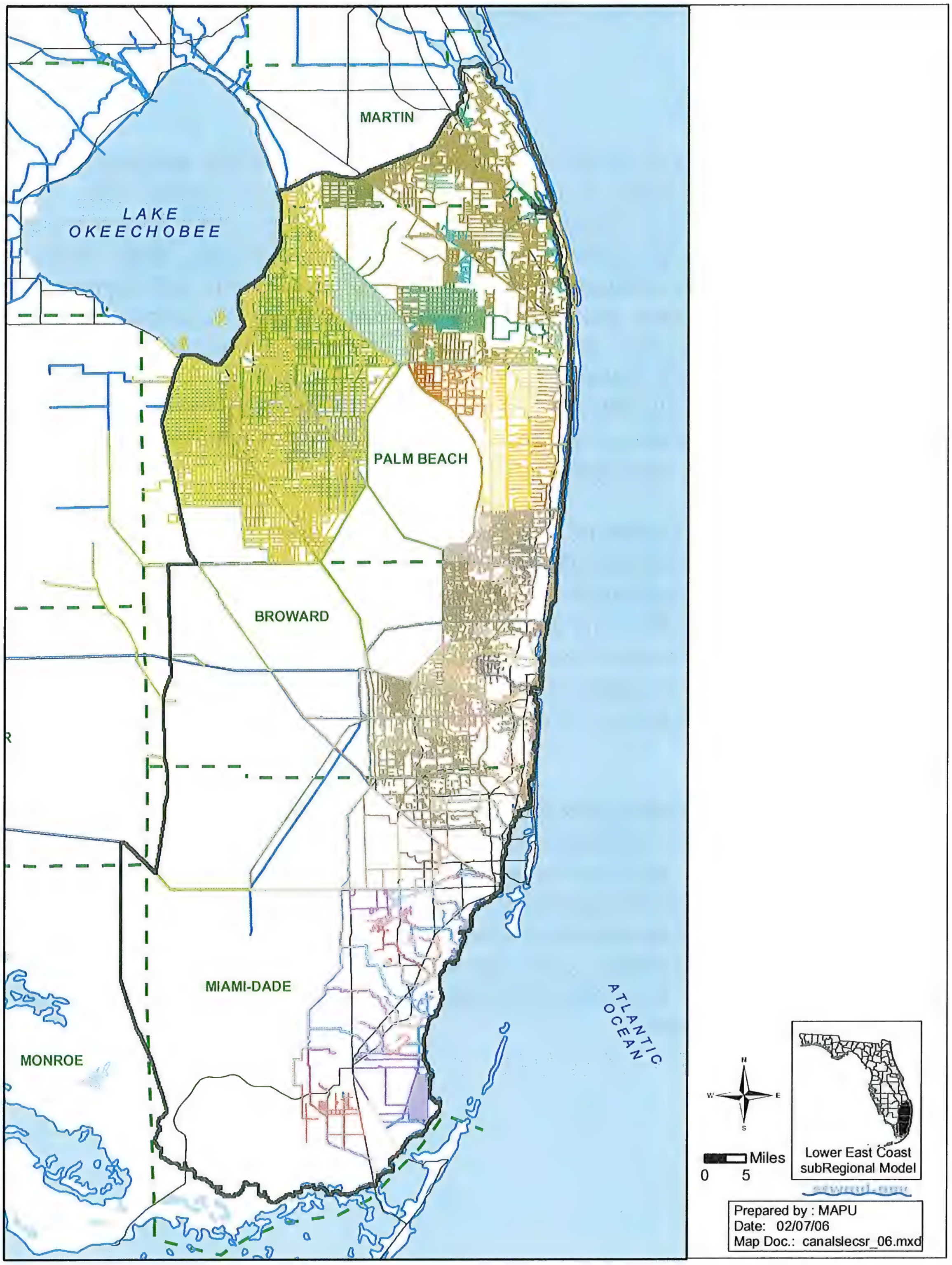


Figure 12. Spatial Variation of Control Levels in Primary, Secondary, and Certain Tertiary Canal Systems. Each Color is Associated with an Operational Rule and/or a Structure.

Regional Flow System Operations

Lake Okeechobee is the primary storage center of the hydrologic system in the LEC; however, its origin is really in the upper Kissimmee Chain of Lakes area in central Florida. Lakes Myrtle, Alligator, Mary Jane, Gentry, East Tohopekaliga, Tohopekaliga, and Kissimmee are the principal sources of inflow to Lake Okeechobee in the upper Kissimmee watershed (**Figure 14**). These lakes flow into the Kissimmee River through the S-65 structure. The Kissimmee River contributes about 69 percent of the inflow to Lake Okeechobee through the S-65E structure at the north end of the lake (Abtew *et al.* 2002). Other major inflow sources to Lake Okeechobee are Lake Istokpoga (through S-68), direct rainfall, Fisheating Creek, the Taylor Creek-Nubbin Slough Basin, reverse flow from the Caloosahatchee River, the St. Lucie Canal, and back pumping from the Everglades Agricultural Area.

Prior to the completion of the North New River, Hillsboro, Miami, and West Palm Beach canals in the early part of the 20th century, water would overflow from Lake Okeechobee and slowly move south through the Everglades wetland system (Sklar *et al.* 2002). Discharges from Lake Okeechobee are now regulated by SFWMD by means of a series of canals and control structures. Outflows from Lake Okeechobee into the LEC occur primarily through structures on the south and southeast side of the lake. Lake levels are managed seasonally to provide flood protection and to meet urban and agricultural water supply demands. During wet periods, seepage from the Everglades is generally more than adequate to maintain water levels in the coastal aquifers; however, releases through coastal canals may be required to maintain regulation schedules in natural storage areas, such as Lake Okeechobee and the WCAs, and to provide flood protection (**Figure 15**). Alternatively, during dry periods additional water may be released from the regional system through the coastal canals to help recharge the Surficial Aquifer System in the coastal basins (**Figure 16**); these water supply releases can be triggered by a decline in canal water levels or by movement of the saltwater front inland (SFWMD 2000).

The four major canals connected to Lake Okeechobee are, from north to south, the West Palm Beach, Hillsboro, North New River, and Miami canals. They route water from Lake Okeechobee through the Everglades Agricultural Area to the south and into Water Conservation Areas (WCAs) 1, 2, and 3 (**Figures 15** and **16**). The WCAs are remnants of the historical Everglades, compartmentalized by canals, levees, and control structures into five separate reservoirs – WCA-1 (known as the Arthur R. Marshall Loxahatchee National Wildlife Refuge), WCA-2A. WCA-2B, WCA-3A, and WCA-3B. The WCAs retain excess floodwaters from Lake Okeechobee, the EAA, and the Everglades, as well as maintaining SAS groundwater levels, reducing saltwater intrusion into coastal basins, and benefiting fish and wildlife (SFWMD 2000).

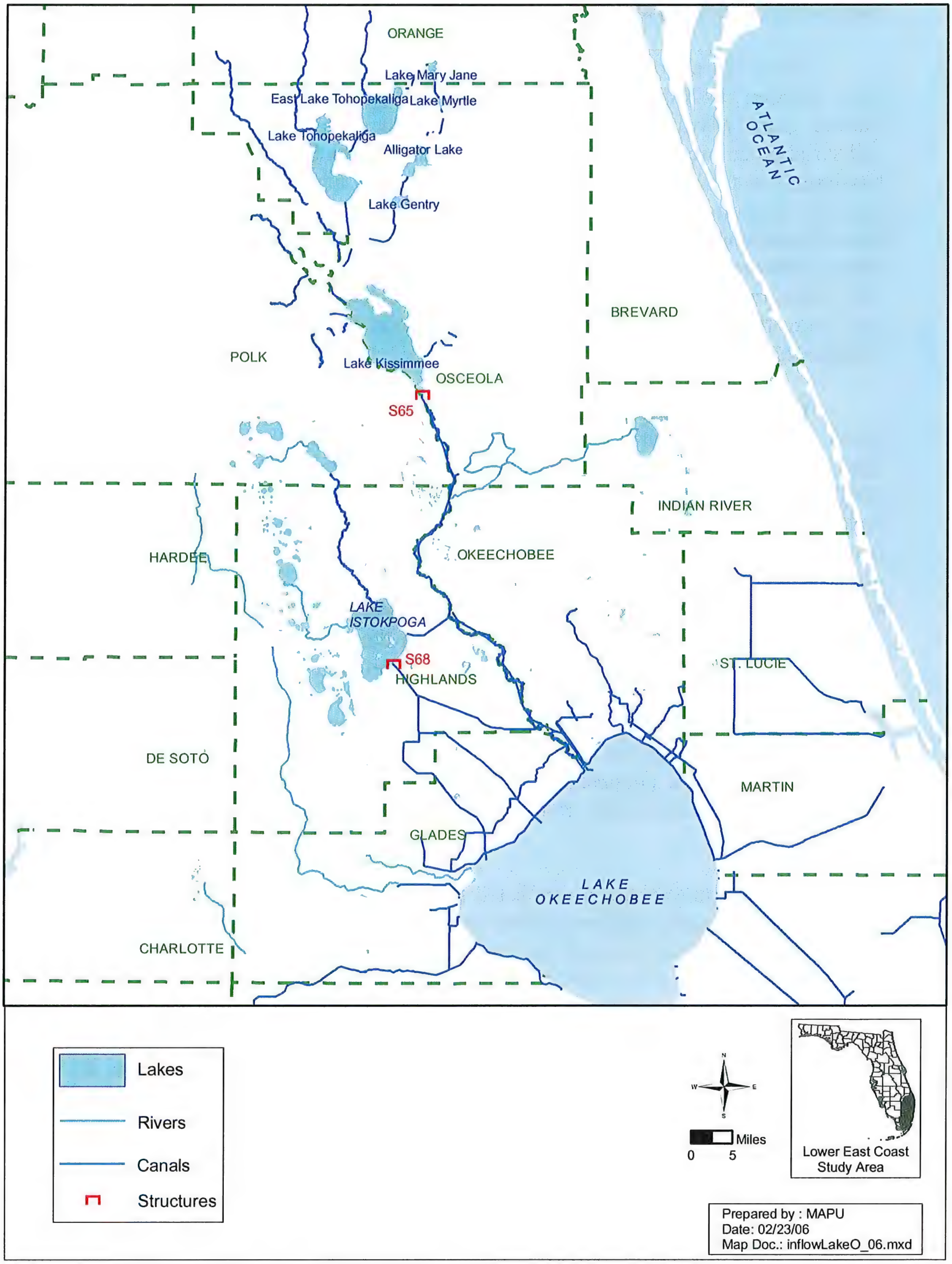


Figure 13. Lakes and Rivers that are Inflow Sources to Lake Okeechobee.

Surface water enters Everglades National Park through the S-12 structures and other structures at the south end of WCA 3 (along the Tamiami Trail), eventually discharging to Florida Bay. A series of canals and structures on the eastern side of the WCAs maintain water levels in the coastal watershed. Coastal canals are regulated to provide flood control, to maintain groundwater levels for municipal wellfields, and to prevent saltwater intrusion.

The opening and closing of the gates on the majority of the operating structures on the canals are controlled remotely from the South Florida Water Management District headquarters. By incorporating the ability to remotely operate the structures with weather radar and satellite images, the District has the ability to quickly drop the water levels in the canals, which improves the existing flood protection for that area.

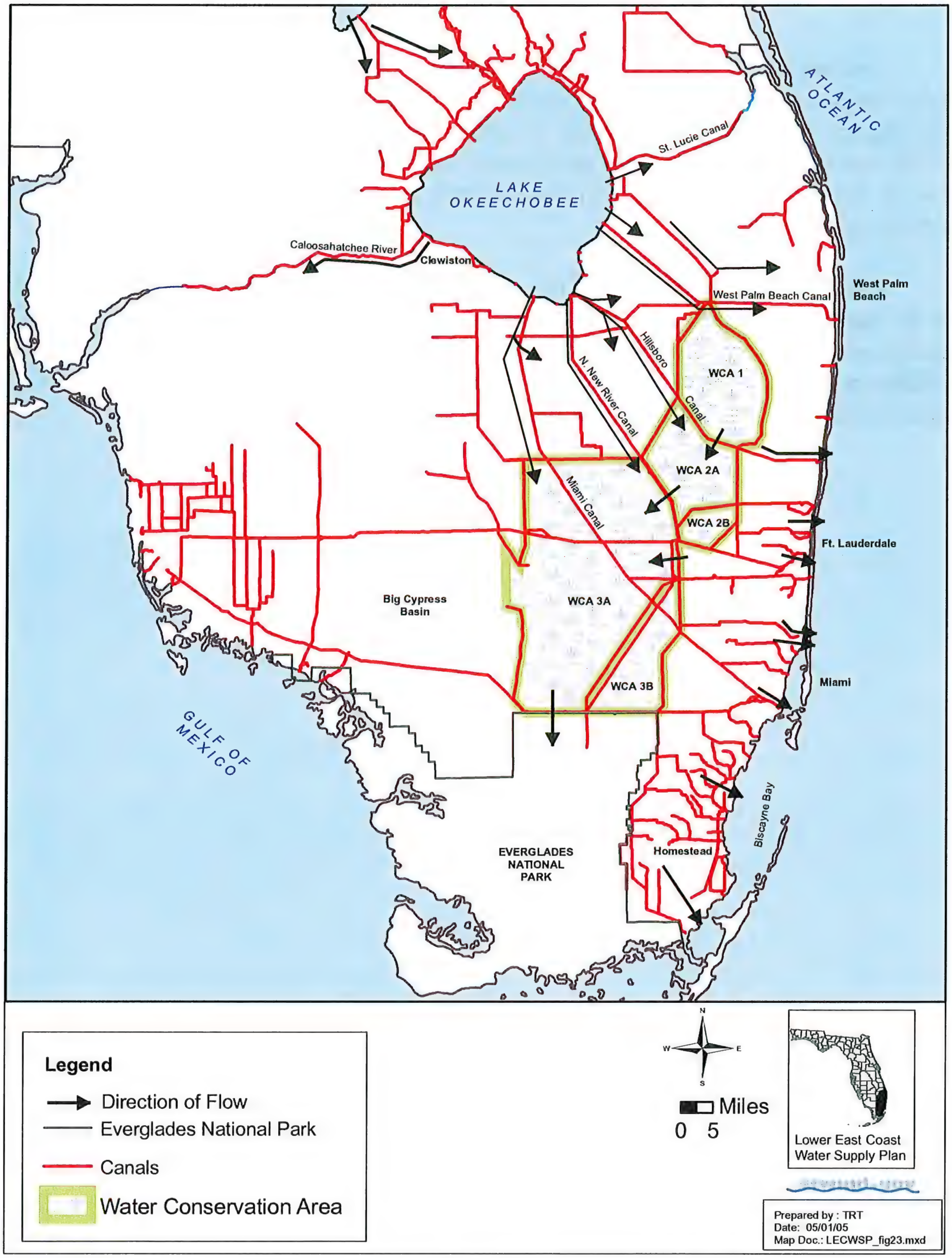


Figure 14. Water Conveyance in the LEC Regional System during Wet Periods. Arrows Indicate Direction of Pumpage or Flow.

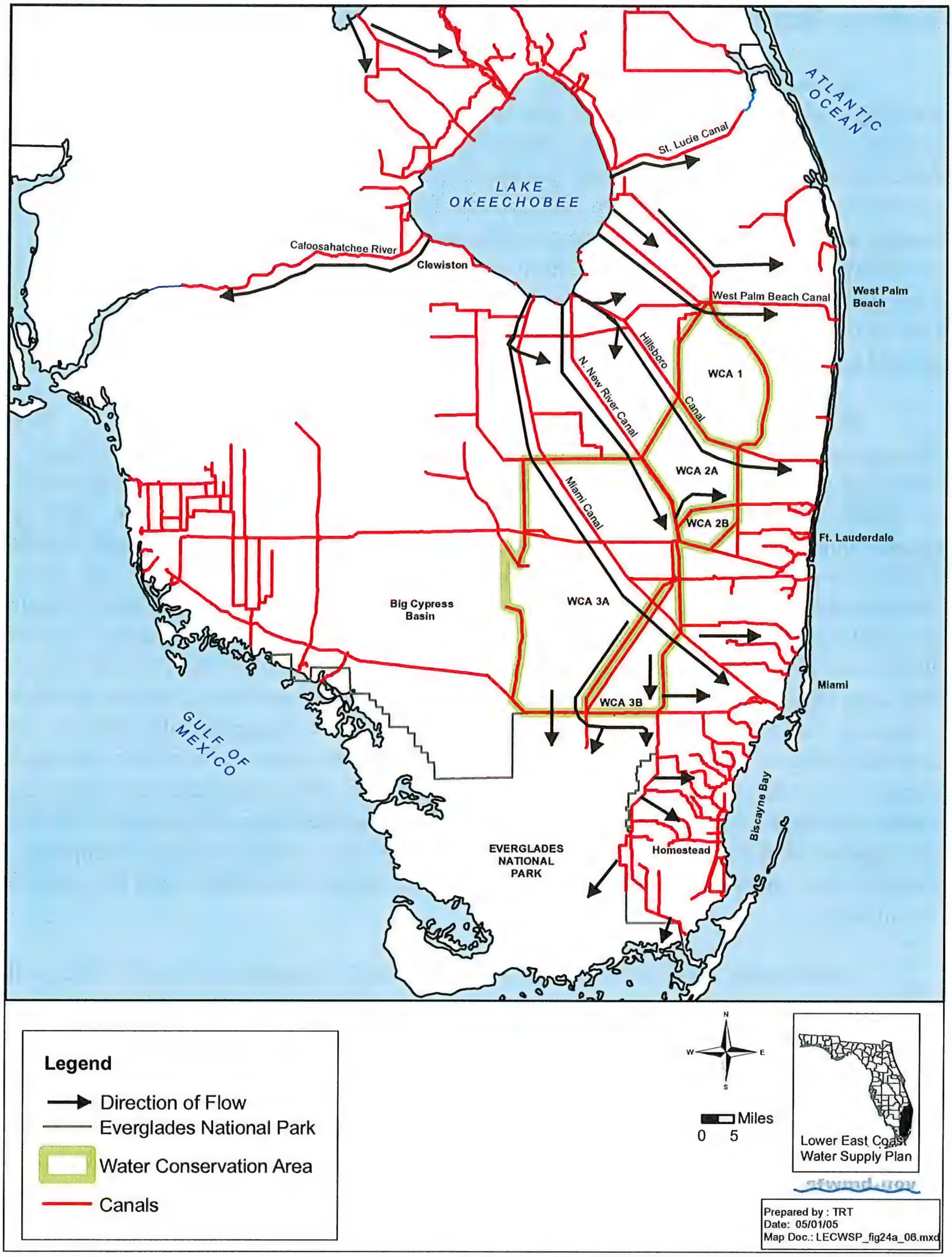


Figure 15. Water Conveyance in the LEC Regional System during Dry Periods. Arrows Indicate Direction of Pumpage or Flow.

Surface Water and Groundwater Interaction

Groundwater levels in the LEC are closely related to surface water levels due to the high hydraulic conductivity of the SAS. The interconnection of surface water and groundwater levels has also been demonstrated from analysis of stable isotope data, which shows that the predominant source of groundwater in a study done in the north-central Everglades (i.e., northern WCAs) was from surface water recharge due to water control operations, historical changes in the water table and land subsidence (Harvey *et al.* 2002). Recharge refers to flow from surface water to groundwater. Conversely, flow from groundwater to surface water is known as discharge. Harvey *et al.* 2004 found that both processes occur in the Everglades when water is exchanged across the wetland ground surface.

Because the predrainage Everglades ecosystem covered a large, uncompartmentalized area with free-flowing water, and with a small change in topography from north to south, the recharge and discharge rates were small (Harvey *et al.* 2004). Currently, the compartmentalization of the WCAs impounds the water and causes larger surface water-groundwater gradients than in the predrainage system. Surface water levels in WCA1 are higher than those in WCA2. Near the levees, groundwater from WCA1 discharges into WCA2 due to the hydraulic gradient. Likewise, groundwater discharges from WCA2 into WCA3 as discussed above. Seepage from the WCAs can also occur west to east as underflow from the WCAs to the protective levees that separate the natural and urban areas. These discharges are intercepted by wellfields located in the eastern, urbanized areas. Harvey *et al.* 2004 recognized that there is little understanding of the source areas, flow paths, and travel times required for Everglades surface water to reach the eastern wellfields and also of how groundwater discharges sustain wetlands during drought. Moreover, the residence times of particles traveling through the shallow, peat sediments will be shorter (i.e., hours to days) compared to particles that travel deeper into the aquifer and emerge at a much later date (i.e., decades to millennia).

Additionally, the SAS and canal system are well connected in the LEC due to the proximity of the canals to the water table and the permeability of the SAS, especially in the Biscayne aquifer. The main purpose of the canal system is to provide flood protection and prevent saltwater intrusion near the coast. Historically, increased pumping lowered water levels and groundwater recharged the canal system. However, saltwater intrusion is mitigated by holding surface water levels higher near the coast, consequently raising adjacent groundwater levels. Initially developed for flood control, the secondary canal structures have allowed the canal network to be used increasingly to regulate ground-water levels by draining the land during wet events and raising canal levels with water from the regional system during droughts. This secondary use has become as important as flood control in water-management practices (Miller 1998). Tertiary canals will provide storage and conveyance for local basin runoff. These canals can be a main source of local recharge into the aquifer system.

HYDROSTRATIGRAPHY AND HYDROGEOLOGY OF SOUTH FLORIDA

Geologic Setting

The basement complex of south Florida is composed of rhyolites and basalts believed to have formed in the vicinity of a Mesozoic hot spot (Heatherington and Mueller 1997). Overlying the volcanic basement rocks is an approximately 20,000-foot thick sequence of carbonates, evaporites and clastic sediments deposited continuously and ranging in age from the Triassic period to the present. Parker *et al.* (1955) and Randazzo (1997) have presented a generalized discussion of the pre-Pleistocene deposits of south Florida. This thick sequence of clastic and carbonate deposits is generally devoid of significant faulting or folding in southern Florida, suggesting a stable tectonic platform. Perkins (1977) has shown that the paleotopographic features of south Florida were inherited from older structural features with no indication of tectonic activity in the region throughout the Pleistocene epoch. In addition, there is no evidence that south Florida was subject to glacial loading during the Pleistocene. Thus, the deposition of the marine units in south Florida must be regulated by eustatic sea level fluctuations associated with glacial and interglacial stages of the Pleistocene rather than tectonic activity or crustal rebound. **Figure 17** illustrates the lithologic units encountered in the study area.

Series	Lithostratigraphic units			Approximate thickness (feet)	Lithology
HOLOCENE	Lake Flirt Marl, Undifferentiated Soil and Sand	H	UNDIFFERENTIATED	0-5	Marl, peat, organic soil, quartz sand
PLEISTOCENE	Pamlico Sand	Q5		0-50	Quartz sand
	Miami Limestone	Q4		0-30	Oolitic and bryozoan limestone
	Fort Thompson Formation	Q3		0-100	Marine limestone and minor gastropod-rich freshwater limestone
	Anastasia Formation	Q2		0-140	Coquina, quartz sand and sandy limestone
	Key Largo Limestone	Q1		0-20	Coralline reef rock
PLIOCENE	Pinecrest Sand Member	T2	Tamiami Formation	0-90	Quartz sand, pelecypod-rich quartz sandstone, terrigenous mudstone
	Ochopee Limestone Member	T1		0-130	Pelecypod lime rudstone and floatstone, pelecypod-rich quartz sand, moldic quartz sandstone
MIOCENE	Peace River Formation		Upper Hawthorn Group	0-300	Clay-rich quartz sand, terrigenous mudstone, diatomaceous mudstone, local abundant phosphate grains

Figure 16. Lithostratigraphic and Geohydrologic Units of the Surficial Aquifer System in Southeast Florida. Source: Adapted from Reese and Cunningham 2000; Perkins 1977.

Quaternary Deposits

Holocene Deposits

The Holocene deposits are the most recently laid sediments and overlay the Anastasia Formation and the uppermost member of the Fort Thompson Formation. These recent deposits of muck, windblown sand, and peat (Parker and Cooke 1944) cover most of the model area from Lake Okeechobee south through the Everglades. Underlying these sediments is the Lake Flirt Marl Formation which is widely distributed throughout the model area. It consists of gray calcareous mud with shells of freshwater snails (Helisoma) and ranges in thickness from a few inches to 3 feet. Lake Flirt Marl underlies the peaty accumulations of the Everglades and overlies the Pamlico Sand formation and other Pleistocene or Pliocene deposits (Cooke 1945).

Pleistocene Deposits

Pleistocene deposits in south Florida are dominated by shallow-water marine carbonates and clastics. Interbedded within these units are indications of sub aerial exposure that include laminated crusts and freshwater limestones (Perkins 1977). Rapid facies changes across the region have resulted in the establishment of several distinct formations even though they appear to have been deposited contemporaneously. The stratigraphy of the Pleistocene sediments utilized in this report follow Parker *et al.* (1955), Brooks (1974) and Perkins (1977). The principal Pleistocene deposits within the study area include the Pamlico Sand, Miami Limestone, Fort Thompson Formation, Anastasia Formation, Caloosahatchee Formation and Key Largo Formation. Each of these deposits may be overlain by recent Holocene deposits.

Pamlico Sand

The Pamlico Sand formation was named by Stephenson (1912) to describe the fine sandy loams, sands and clays from Pamlico Sound in North Carolina. Parker and Cooke (1944) extended the Pamlico formation into Florida to include all marine Pleistocene deposits younger than the Anastasia Formation.

The Pamlico Sand Formation unconformably overlies the Miami Limestone, Anastasia Formation, and Fort Thompson Formation and covers most of the region south of Lake Okeechobee. The formation does not usually extend above the 25-foot contour, which was the approximate shore line location of the third interglacial stage (Cooke 1952). The formation is primarily composed of quartz sand with some local bodies of clay. The Lake Flirt Marl and recent deposits of muck, peat, and windblown sand overlie the Pamlico Sand (Parker and Cooke 1944).

Miami Limestone

The Miami Oolite was studied in the mid to late 1800s by Tuomey (1851), L. Agassiz (1852), Shaler (1890), A. Agassiz (1895, 1896) and Griswold (1896). In 1909, Sanford proposed the name Miami Oolite for the oolitic deposits in the vicinity of Miami. However, Sanford (1909) separated the mainland oolite from the oolite found in the lower Keys. Later, Cooke and Mossom (1929) redefined the Miami Oolite to include all oolitic deposits in south Florida, including those found in the Florida Bay and the Florida Keys. Hoffmeister *et al.* (1967) suggested that the name be changed to the Miami Limestone based upon two distinct members, an upper oolitic facies and a lower Schizolle floridana bryozoan facies.

The Miami Limestone unconformably overlies the Fort Thompson Formation (Perkins 1969) and is generally less than 20-feet thick but can exceed 40-feet thick along the coast in Miami. The oolites were deposited in a shallow sea similar to present conditions along the Bahama Bank, and this deposit has been dated at 125,000 years BP by Osmond *et al.* (1965) and Broecker and Thurber (1965). The unit encompasses a broad arc shape from Boca Raton southward through Miami and terminates in the vicinity of the Key West/Dry Tortugas area.

Fort Thompson Formation

As originally proposed by Sellards (1919), the Fort Thompson Formation consists of alternating beds of marine, brackish and freshwater limestones located at the type location along the Caloosahatchee River. Although Sellards (1919) originally called this outcrop the Fort Thompson beds, Cooke and Mossom (1929) gave it formational status. The unit overlies the Caloosahatchee Marl in the northwest portion of the study area but lies directly above the Tamiami Formation through the vast majority of the study area., and is Pleistocene in age (Cooke and Parker 1944; Mitterer 1975). The formation inter-fingers with the Anastasia and Key Largo Formations on the eastern and southern boundaries.

The Formation may be subdivided into four distinct members. The uppermost unit, termed the Coffee Mill Hammock member, is a marine unit characterized by abundant Chione cancellata mollusks. The unit grades into clastic beach and bar deposits of the Anastasia Formation eastward and into the carbonate oolitic shoal deposits of the Miami Limestone southward. Beneath the Coffee Mill Hammock member is Unit 1 of Brooks (1974). This unit is characterized by mollusk packstones and wackestones, including Chione cancellata. The clastic content decreases southward, transitioning from a shallow marine bay into an open marine platform environment (Perkins 1977). The lower middle unit, Unit 2 of Brooks (1974), is similar to Unit 1 but contains a very pronounced discontinuity surface between the units. Arenaceous, mollusk-fragment packstones characterize this unit, suggesting a restricted marine bay environment (Perkins 1977). The lowermost unit of the Fort Thompson Formation, Unit 3 of Brooks, has an increased clastic content compared to the overlying units, with mollusk-fragment

packstones and quartz sandstones common (Perkins 1977). The depositional environment appears to suggest an extensive somewhat restrictive marine bay (Perkins 1977).

The depositional environment of the Fort Thompson Formation can be linked to late Quaternary sea level fluctuations. Parker and Cooke (1944) identified five separate marine invasions in this formation punctuated by freshwater deposition or subaerial exposure between the marine transgressions. Amino acid racemization work conducted by Mitterer (1975) revealed that three of the beds are late Pleistocene in age, ranging from 134,000 years before present (BP) to 324,000 BP. The age of the lowermost unit could not be determined using Mitterer's (1975) methodology.

The Fort Thompson Formation covers the largest geographic expanse of all Quaternary formations in south Florida. The unit is generally less than 10-feet thick at the Caloosahatchee River but increases to over 50-feet thick in eastern Miami-Dade, Broward and Palm Beach Counties, where it makes up the highly productive zone of the Biscayne aquifer (Fish and Stewart 1989). This formation can be found in all areas of south Florida with the possible exception of the coast in Palm Beach County where it inter-fingers with the lower members of the Anastasia Formation.

Anastasia Formation

Originally named by Sellards (1912) for a series of coquina outcrops on Anastasia Island off the east coast of north Florida, the Anastasia Formation was extended by Cooke and Mossom (1929) to include all marine deposits located along the coast from Palm Beach County northward. The deposit consists of alternating offshore bar, beach ridge and dune system environments and may be at least 50 feet thick along the coast (Perkins 1977). The age of the formation is estimated to be late Pleistocene and is considered to be deposited contemporaneously with the Miami Limestone and Fort Thompson Formation (Parker *et al.* 1955). The formation general lies directly upon the Tamiami Formation.

The Anastasia Formation can be divided into two distinct facies, a coquina facies and a shell rock facies (Lovejoy 1983). The coquina facies represents a high energy environment typical of an offshore bar complex and is generally aligned with the present coastline. Behind this bar complex is the shell rock facies characterized by a diverse molluscan fauna with minimal damage to the fossils in a fine-grained quartz matrix, suggesting a shallow bay origin (Lovejoy 1983).

Caloosahatchee Formation

The Caloosahatchee beds or marls were considered the lower shell beds along the upper portion of the Caloosahatchee River by Dall (1897). The formation was officially named the Caloosahatchee Marl by Matson and Clap (1909). The age of the formation is believed to be late Pliocene to early Pleistocene. The formation occurs from Saint Petersburg on the west coast, southeast past the Caloosahatchee River, to the east coast (Randazzo, 1997). The formation generally thickens toward the east coast (Parker and

Cooke, 1944). Within Palm Beach County, however, the unit is restricted to the western part of the model area where it may directly underlie the Fort Thompson, Anastasia or Holocene sediments. The Formation is restricted to the northwestern portion of the study area in the vicinity of Lake Okeechobee. It consists of sandy, shelly marls, silt and clay with occasional stringers of well-consolidated sandy limestone.

Key Largo Limestone

Sanford (1909) proposed the name Key Largo Limestone for a coralline limestone exposed on Key Largo, Florida. This coralline limestone composes the upper Florida Keys from Soldier Key southward to Bahia Honda. The Key Largo Limestone also interfingers with the Miami Limestone along the western edge of Biscayne Bay. The formation is dominated by the corals Monsterea and Diplora, indicating an inner reef depositional environment (Hoffmeister 1975). The age of upper unit has been dated as approximately 125,000 years BP (Osmond *et al.* 1965; Broeker and Thurber 1965).

Tertiary Deposits

Tamiami Formation

The Tamiami Formation, originally named by Mansfield (1930), is the principal Tertiary deposit in the LECsR model area. The formation covers most of south Florida from Lake Okeechobee southward and stretching across the entire State from the Gulf of Mexico to the Atlantic Ocean. It outcrops in the general vicinity of Naples and the Ten Thousand Islands and dips eastward and northward. The formation thickens to the east and the southeast. It inter-fingers with the Caloosahatchee Formation (Parker and Cooke, 1944). The two primary members of the Formation are the Pinecrest Sand Member and the Ochopee Limestone Member. It is primarily composed of sandy limestone, calcareous sandstone, quartz sand, clay and marl, and often contains solution holes filled with soil (Parker and Cooke, 1944). The formation was deposited during the Pliocene to late Miocene epoch. The upper Tamiami Pliocene deposits

Pliocene Deposits

Pinecrest Sand Member

The Pinecrest sand members originally named Pinecrest beds by Olsson(1964). Pinecrest sand is well sorted with abundant well preserved shells (Scott, 1992). The Pinecrest sand member has three lithofacies: 1) Quartz and sand, 2) rudstone and floatstone and 3) mudstone. The quartz and sand is the most characteristic of the Pinecrest sand member (Reese and Cunningham, 2000). The Pinecrest sand member is thickest in central and south-central Miami-Dade County.

Ochopee Limestone Member

The Ochopee Limestone Member is made up of limestone composed of very fine to fine quartz grains (Reese and Cunningham, 2000). The Ochopee Limestone is well indurated, phosphatic and variably sandy (Scott, 1992) The Ochopee Limestone is thickest in southwest Palm Beach County and northwest Broward (Reese and Cunningham, 2000). In Miami-Dade County the Ochopee Limestone pinches out and transitions to the overlying Pinecrest Sand (Reese and Cunningham, 2000).

Miocene Deposits

Unnamed Formation

The boundary between the Tamiami Formations Ochopee Limestone and the Peace River Formation is composed of a combination of quartz, gravel, sand, silt and carbonate rocks. At bottom of the formation is clean sand (Reese and Cunningham, 2000).

Peace River Formation

The Hawthorn Group is composed of an upper and lower formation. The top of the Upper Hawthorn is the Peace River Formation. The Peace River Formation is principally carbonic rocks with siliciclastic sediment (Scott, 1990, Reese and Cunningham, 2000) interbedded with quartz, sand and clay. This represents the base of the SAS and concludes our description of the Hawthron Group.

Chronostratigraphy

Chronostratigraphy is the study of the ages of strata and may include the correlation of strata using relative or absolute methods of age determination. Large areas of south Florida are marine carbonate deposits. Emergence of these deposits by a reduction in sea level subjects the carbonate deposits to atmospheric conditions. The correlation of these marine units across the study area provides an indication of areas where potential reduced vertical movement of water may occur in the groundwater system.

The development of advanced groundwater flow models to accurately simulate subsurface conditions in south Florida requires the vertical discretization of the Surficial Aquifer System (SAS) into an appropriate layering scheme. Historically, discretization of the SAS has generally fallen along hydrologic lines with minimal consideration for stratigraphic boundaries (Restrepo *et al.* 1992; Merritt 1998). Although previous approaches resulted in an adequate calibration for the model simulation periods, the layer schemes tended to cross distinct depositional boundaries and occasionally even formational boundaries. The approach utilized herein delineates the layering scheme

along the stratigraphic boundaries originally proposed by Perkins (1977) while preserving the hydrologic properties of the aquifer system.

The sediments deposited during the Quaternary Period are important to the interpretation of the stratigraphy of the SAS. The Quaternary sediments appear to have been deposited during the middle to late Quaternary Period. Within the Quaternary sediments, there are several episodes of subaerial exposure that resulted from the low sea level stands associated with Pleistocene glacial advances. Depositional indicators of these subaerial exposure periods include the development of dense caliche-type crusts with localized deposits of freshwater limestones on the underlying marine limestones. These caliche-type crusts generally have moderate to low hydraulic conductivities, and represent significant departures from the extremely permeable marine limestones generally located above and below these units. These subaerial exposure zones tend to retard vertical movement of water.

Identification of these subaerial exposure surfaces becomes a critical component for the stratigraphic subdivision of the Quaternary sediments within the study area. Perkins (1977) indicates that these zones may only be deposited within a 6-inch to 1-foot layer. Therefore, geologic logs based on cuttings collected at 5-foot intervals or where the geologist was not specifically documenting subaerial exposure surfaces are not very useful for this type of analysis. Detailed continuous geologic logs are required to identify these subaerial exposure surfaces.

In addition to the lithologic descriptions of the strata, age estimates are required to correlate the marine beds within a formation to world-wide eustatic sea level fluctuations. Parker and Cooke (1944) attempted to correlate a series of marine deposits located along the river bank of the Caloosahatchee River in south Florida to interglacial periods of the Pleistocene. Parker *et al.* (1955) refined the formational breaks in south Florida based, in part, on the earlier division proposed by Parker and Cooke (1944). Brooks (1968) subsequently refined the number of interglacial marine deposits of Pleistocene age. Building on the findings of these and other authors, Perkins (1977) differentiated the various Quaternary deposits of southeastern Florida into five distinct marine units punctuated by episodes of subaerial exposure (Q1, Q2, Q3, Q4, and Q5 in **Figure 25**). The estimated age of the uppermost marine unit was assigned based on radiometric dating of the Key Largo Limestone and Miami Limestone (Osmond *et al.* 1965; Broecker and Thurber 1965). Dates for the remaining four Quaternary units were estimated from amino acid racemization results from the Fort Thompson Formation (Mitterer 1975).

Correlation of marine beds to oxygen isotope stages provides an understanding of the length of time the upper surfaces may have been exposed to terrestrial processes and also allows for an understanding of the facies distribution and paleotopography across the study area during a single marine transgression (Perkins 1977).

Facies distribution and secondary solutioning also help control the hydraulic properties of the SAS. For example, buried in-situ reef systems may exist adjacent to sandy shallow marine flats. Although both facies may have been deposited during a

single high sea level stand, their hydraulic properties may be significantly different. Identification of facies distributions and general aquifer parameters associated with the individual facies need to be recognized prior to discretization of the model to allow for accurate simulation of the SAS.

The tops and bottoms of the Holocene, the 5 Q Units, and the two Members of the Tamiami Formation were determined from a variety of sources including Caursas (1985), Caursas (1987), Reese and Cunningham (2002), Harvey *et al* (2000), and Giddings (1999). However, Perkins (1971) was used as the primary source.

Figure 18 represents the location of five cross sections across the study area showing only the thickness of the Holocene sediments, Q Units 1 through 5, and the Pinecrest and Ochopee members of the Tamiami Formation. Only thickness of the units is shown to identify potential tops where sub-aerial exposure surfaces may occur. **Figure**s **19**, **20** and **21** are oriented in a north-south direction. No noticeable change occurs regarding the base of the SAS from north to south, although there appears to be a slight thinning northward. The Holocene sediments are extremely thin when compared to the Quaternary and Tertiary Sediments. The Tamiami Formation is the dominant formation along the west portions of the study area. The Quaternary sediments begin to thicken in **Figure 20** and eventually are thickest along the coast (**Figure 21**). Deposition within the Quaternary sediments is relatively consistent although Q Units 2 and 3 appear to have had thicker depositional periods in many wells especially along the coast.

Figures **22** and **23** are cross sections with an east-west orientation across the study area. These two **Figure**s illustrate the drastic increase in thickness of the Quaternary sediments, and the thinning of the Tamiami Formation from east to west across the study area. The Quaternary Period appears to include the additional eastward expansion of the southeastern Florida peninsula.

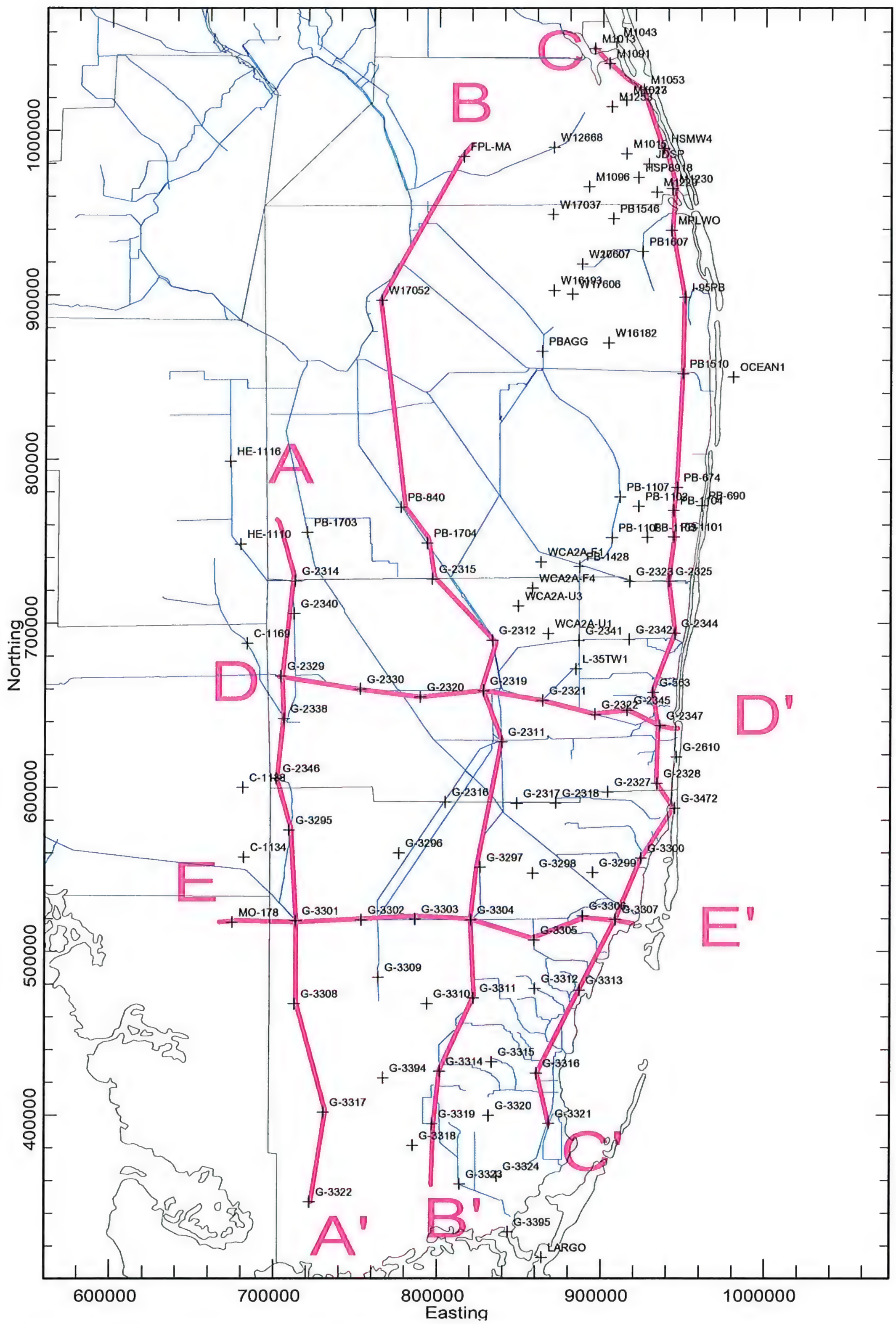


Figure 17. Cross-section Base Map.

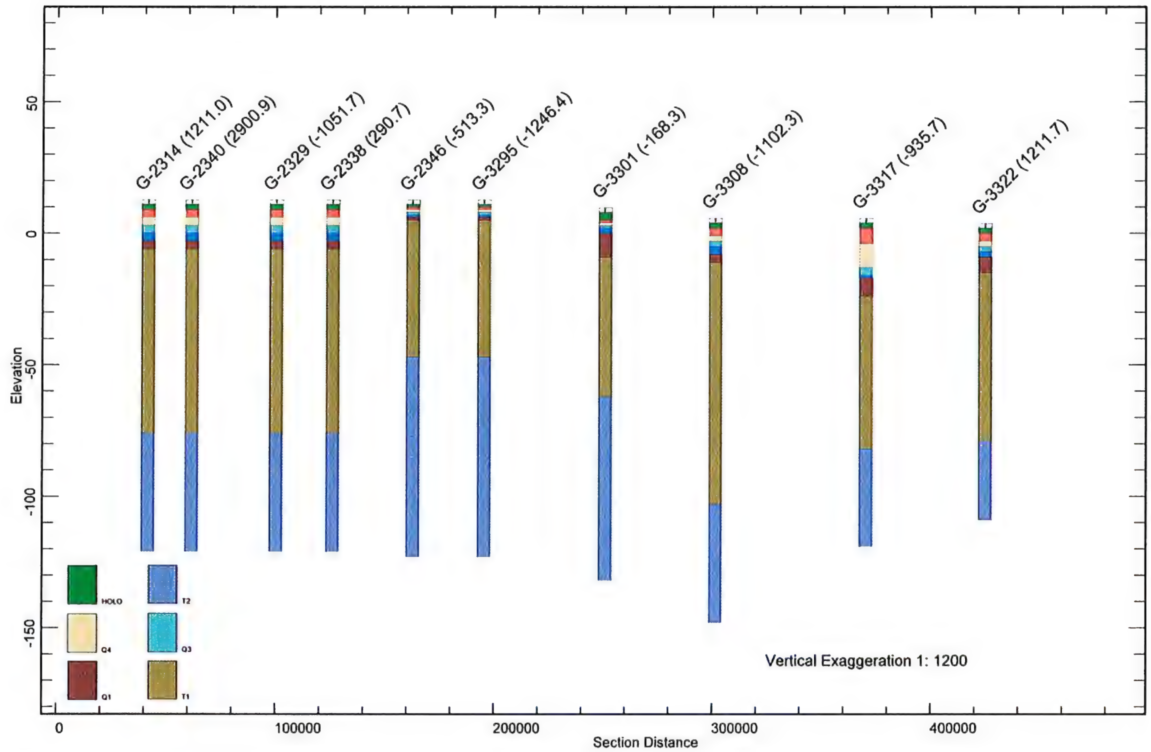


Figure 18. Cross-section A-A'.

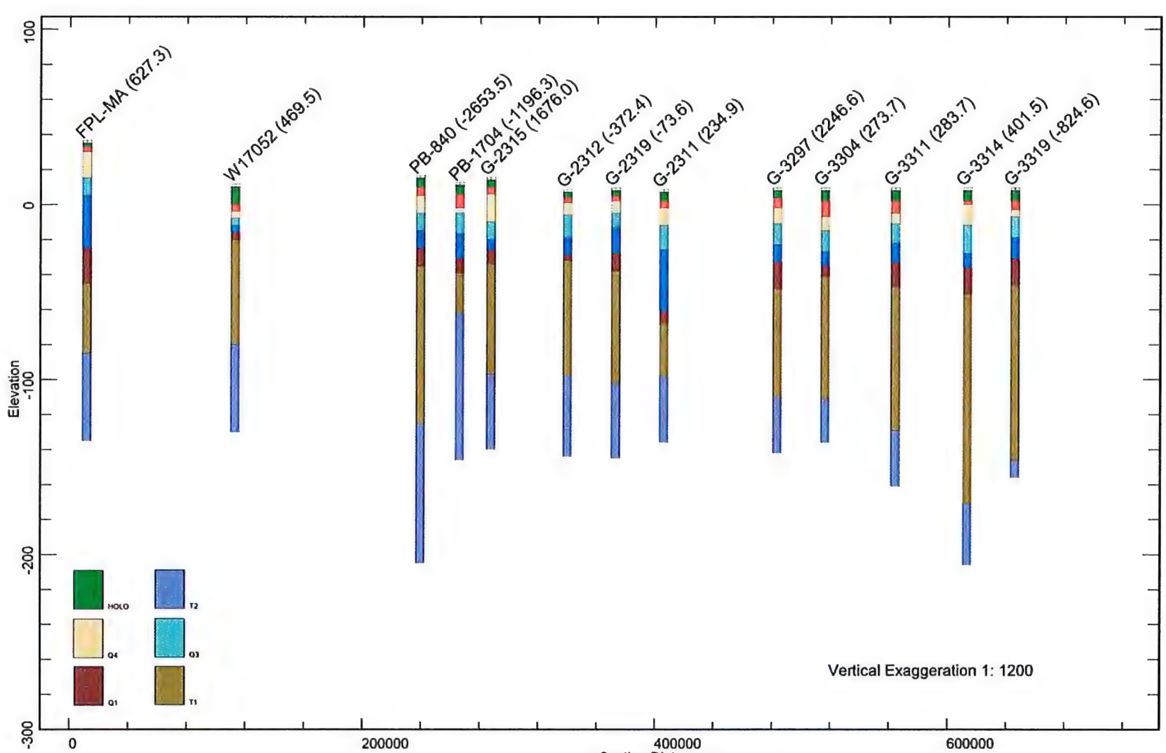


Figure 19. Cross-section B-B'.

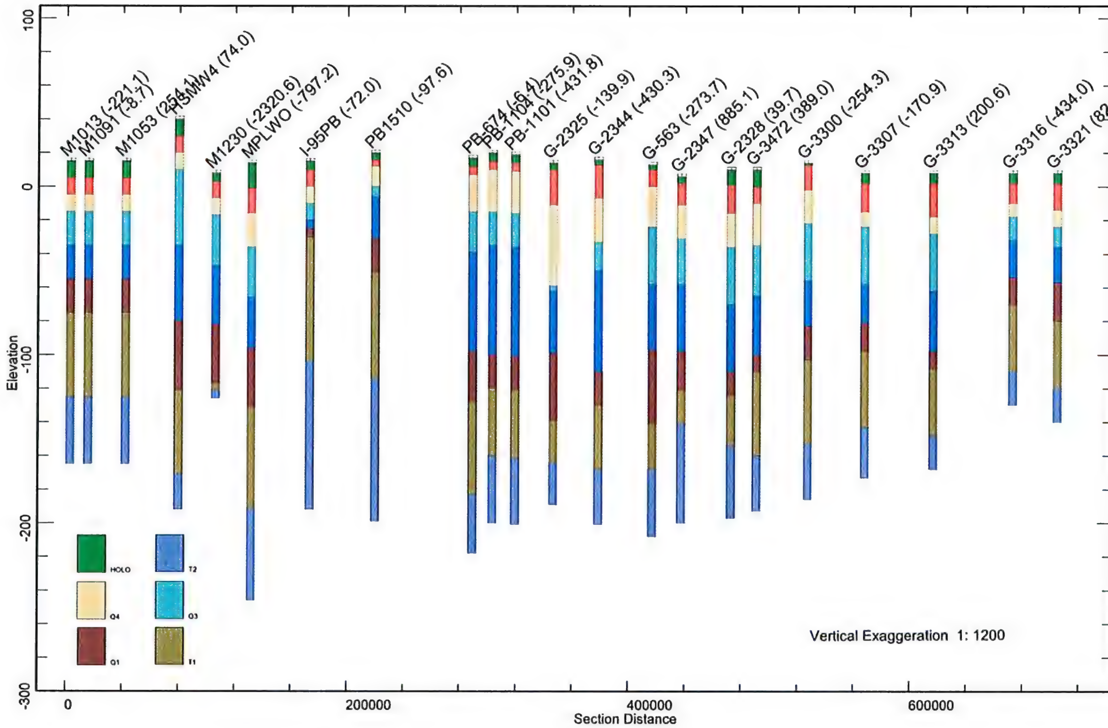


Figure 20. Cross-section C-C'.

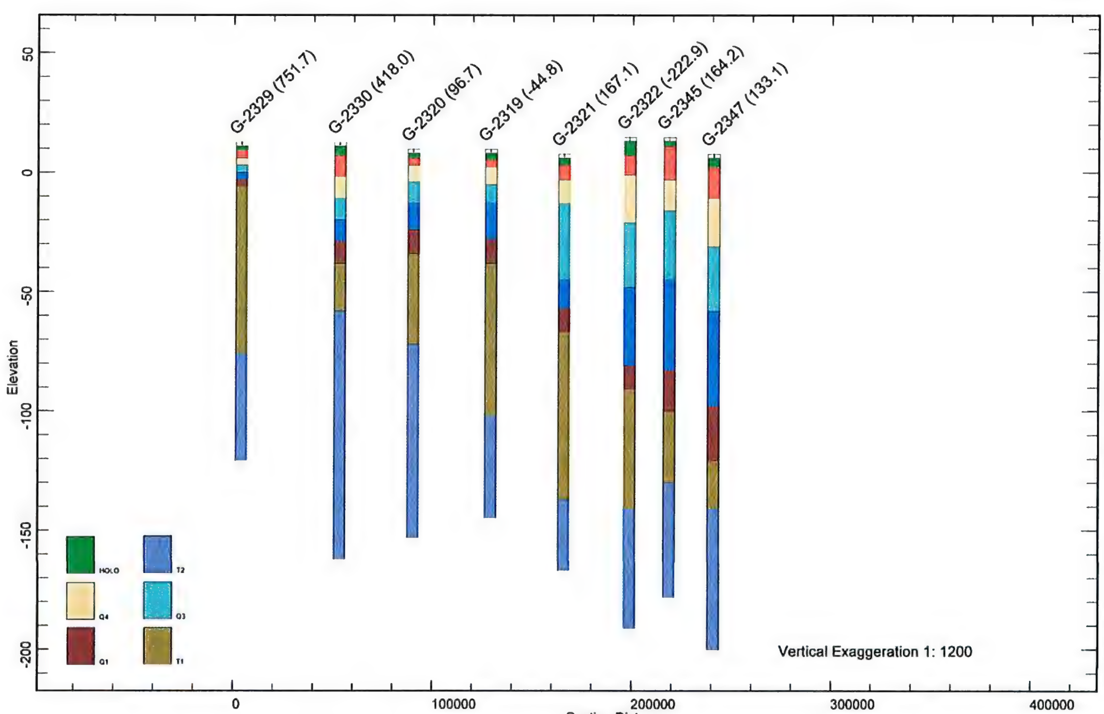


Figure 21. Cross-section D-D'.

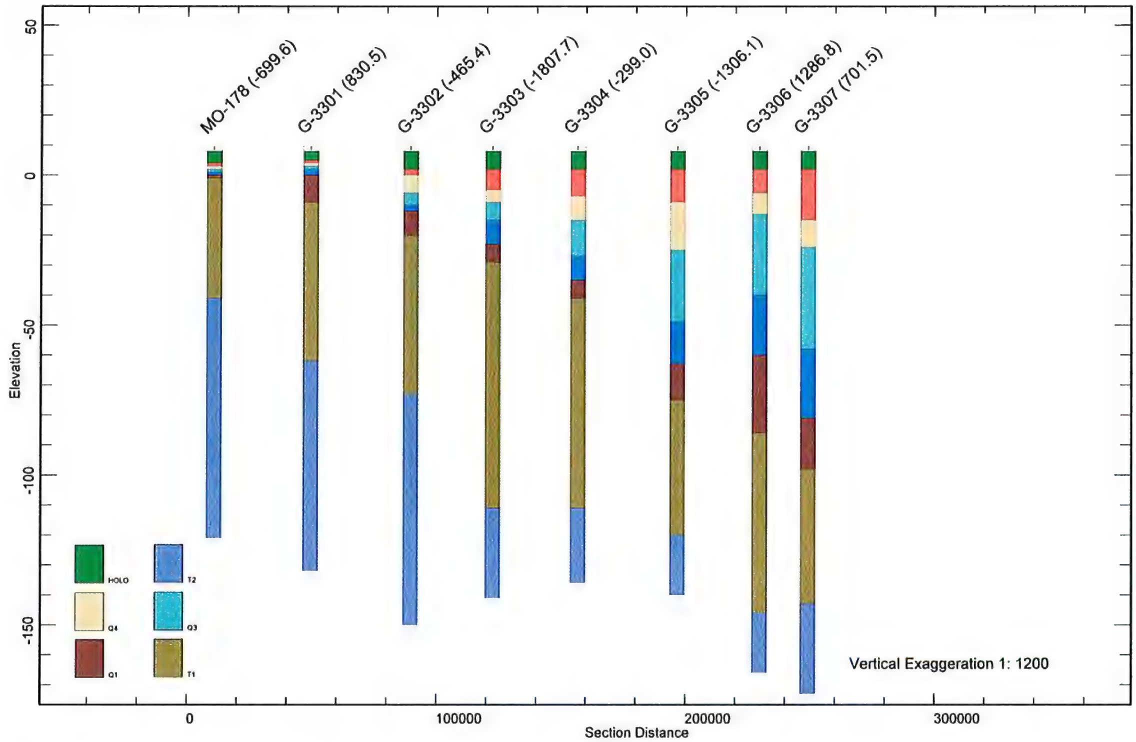


Figure 22. Cross-section E-E'.

Groundwater Hydrology of the Surficial Aquifer System

The Surficial Aquifer System (SAS) is an unconfined to semi-confined aquifer system, and includes all saturated sediments from the ground surface down to the clay and marls of the impermeable Hawthorn Group. The system is dominated by carbonate and clastic sediments ranging in age from the Holocene through the Miocene. The limestone beds constitute the major water-producing component of two aquifers: the Biscayne aquifer and the Gray Limestone aquifer. These two aquifers can grade into one another, especially along the coast. The SAS includes a composite of the Biscayne aquifer, the Gray Limestone aquifer along the coast, and the Water Table aquifer.

The Biscayne aquifer generally comprises all Quaternary sediments including, the Fort Thompson Formation, Anastasia Formation and Miami Limestone (Fish 1988). The Gray Limestone aquifer is a permeable zone within the Tamiami Formation of Pliocene to Miocene age (Fish and Stewart 1991). In western Broward and Miami Dade Counties, the Biscayne aquifer is separated from the lower Gray Limestone aquifer by a semiconfining unit of the upper Tamiami Formation, with the two aquifers merging into a single hydrologic unit along the coast. The remaining portion of the SAS, the Water Table aquifer, has much lower yields than the Biscayne and Gray Limestone aquifers, and is located in western and northern Palm Beach County and all of Martin County.

Biscayne Aquifer

The principal groundwater resource for the southeast coast of Florida is the Biscayne aquifer. This groundwater system provides most of the fresh water for public water supply and irrigation demands within the model area, and is also used to maintain canal and lake systems as well as provide groundwater base flows to the Everglades and important estuaries including Biscayne Bay and Florida Bay. The Biscayne aquifer is an unconfined aquifer and a component of the SAS underlying most of southeast Florida as shown in **Figures 3** and **24**.

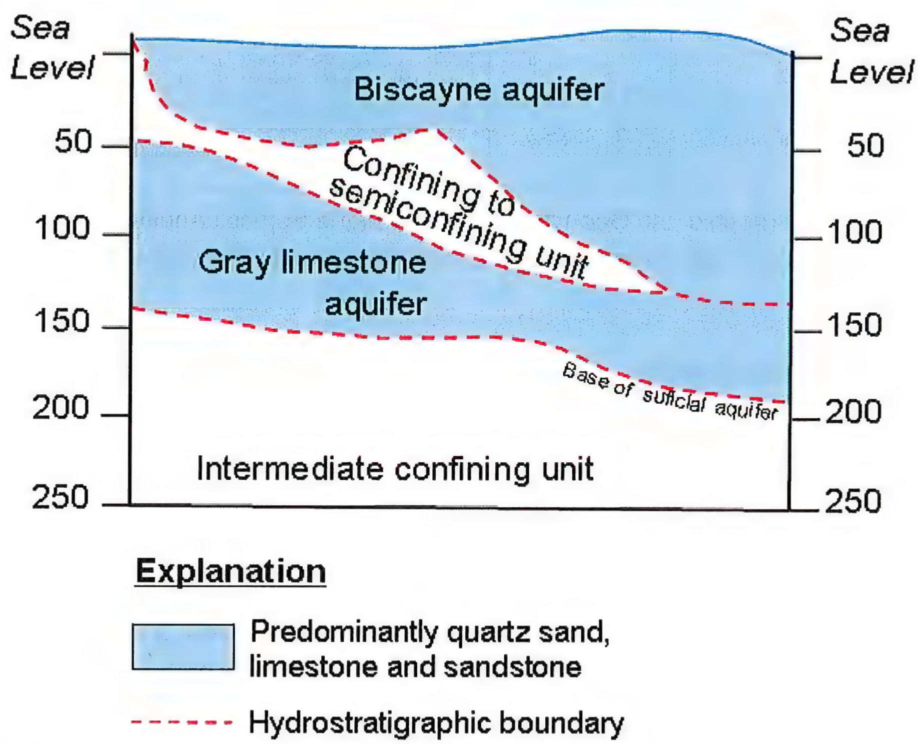


Figure 23. Geologic Cross-Section of the Surficial Aquifer System in Southeast Florida.

The major geologic deposits that comprise the Biscayne aquifer include the Miami Limestone, Fort Thompson Formation, Key Largo Formation and the Anastasia Formation. Information about these deposits is summarized in **Figure 25**. The base of the Biscayne aquifer is generally the contact between the Quaternary Fort Thompson Formation and the Pliocene-Miocene Tamiami Formation.

The Biscayne aquifer is composed of interbedded, unconsolidated sands and shell units along (in combination) with varying thicknesses of consolidated, highly solutioned limestones and sandstones (Shine *et al.* 1989). In general, the Biscayne aquifer contains a smaller percentage of sand and a greater percentage of solutioned limestone than the other portions of the SAS. The Biscayne aquifer is one of the most permeable aquifers in the world, with estimated transmissivities in excess of 7 million gallons per day, per foot of drawdown (Parker *et al.* 1955).

Series	Lithostratigraphic units			Approximate thickness (feet)	Lithology		Hydrologic unit	Approximate thickness (feet)
HOLOCENE	Lake Flirt Marl, Undifferentiated Soil and Sand	H	UNDIFFERENTIATED	0-5	Marl, peat, organic soil, quartz sand	SURFICIAL AQUIFER SYSTEM	Water Table Aquifer	0-120
PLEISTOCENE	Pamlico Sand	Q5		0-50	Quartz sand			
	Miami Limestone	Q4		0-30	Oolitic and bryozoan limestone			
	Fort Thompson Formation	Q3		0-100	Marine limestone and minor gastropod-rich freshwater limestone			
	Anastasia Formation	Q2		0-140	Coquina, quartz sand and sandy limestone		Biscayne Aquifer	
	Key Largo Limestone	Q1		0-20	Coralline reef rock			
PLIOCENE	Pinecrest Sand Member	T2	Tamiami Formation	0-90	Quartz sand, pelecypod-rich quartz sandstone, terrigenous mudstone		Upper Semiconfining to Confining Unit	0-130
	Ochopee Limestone Member	T1		0-130	Pelecypod lime rudstone and floatstone, pelecypod-rich quartz sand, moldic quartz sandstone		Gray Limestone or Lower Tamiami Aquifer	0-130
MIOCENE	Peace River Formation		Upper Hawthorn Group	0-300	Clay-rich quartz sand, terrigenous mudstone, diatomaceous mudstone, local abundant phosphate grains		Intermediate Confining Unit or Intermediate Aquifer System	300 ±

Figure 24. Lithostratigraphic and Geohydrologic Units of the Surficial Aquifer System in Southeast Florida. Source: Adapted from Reese and Cunningham 2000; Perkins 1977.

Gray Limestone Aquifer

Underlying the Biscayne aquifer and composing the base of the SAS is the Tamiami Formation. This formation consists of an upper clastic unit with low to moderate permeability. Beneath the upper clastic unit is an intermediate limestone unit locally referred to as the Gray Limestone aquifer or an eastern extension of the Lower Tamiami aquifer which is characterized by moderate to high permeability. The Gray Limestone aquifer is located in the western portion of the study area where it is semi-confined to unconfined. In the eastern portion of the study area it interfingers with the Biscayne and Water Table aquifers to form the SAS. The base of the SAS is also generally considered to be the base of the Tamiami Formation, which consists of a lower clastic unit of moderate to low permeability (Fish and Stewart 1991).

The Gray Limestone aquifer includes the Ochopee Limestone Member of the Tamiami Formation. It is overlain and underlain by upper and lower confining to semiconfining units throughout most of the Lower East Coast of Florida. These confining units are usually composed of siliclastics of low to very low hydraulic conductivity (Reese and Cunningham 2000).

Hydrogeologic Parameters

Aquifers transmit water at a rate based upon hydraulic conductivity, storage properties, and the hydraulic gradient. Henry Darcy first introduced an equation in 1856 to express factors controlling the movement of groundwater. This equation, known as Darcy's Law, is expressed as follows:

$$Q = KA\frac{\partial h}{\partial l}$$

Where Q is the quantity of water, K is the hydraulic conductivity, A is the cross-sectional area at a perpendicular to the flow direction, and the hydraulic gradient is the change in head per change in length, dh/dl.

The primary aquifer characteristics required for simulating flow in an unconfined aquifer are transmissivity and specific yield. Transmissivity is the capacity of an aquifer to transmit water and is determined by multiplying the hydraulic conductivity of the aquifer by the thickness of the aquifer. Darcy's Law can be rewritten in terms of transmissivity by expressing the cross-sectional area component of the equation as the product of the width, w and the aquifer thickness, b. The revised equation is as follows:

$$Q = Tw\frac{\partial h}{\partial l}$$

Therefore, in order to solve the groundwater flow equation, the hydraulic conductivity, the aquifer thickness or the transmissivity of the aquifer will need to be identified. These parameters are generally determined from doing some form of aquifer performance test (APT) on wells with known aquifer and screen interval depths and pumping rates. Laboratory analysis can also help determine some estimated properties of the aquifer as well. In the study area, there are three types of data that will be used to determine the hydraulic conductivity and aquifer thicknesses. They are geologic control wells with continuous cores, APT's, and specific capacity tests on existing production wells. Locations of the three data types used to estimate hydraulic conductivity are shown in **Figure 26**. The hydraulic conductivities derived from the Holocene, five Quaternary, and Tertiary units are depicted in **Figures 27** to **36**.

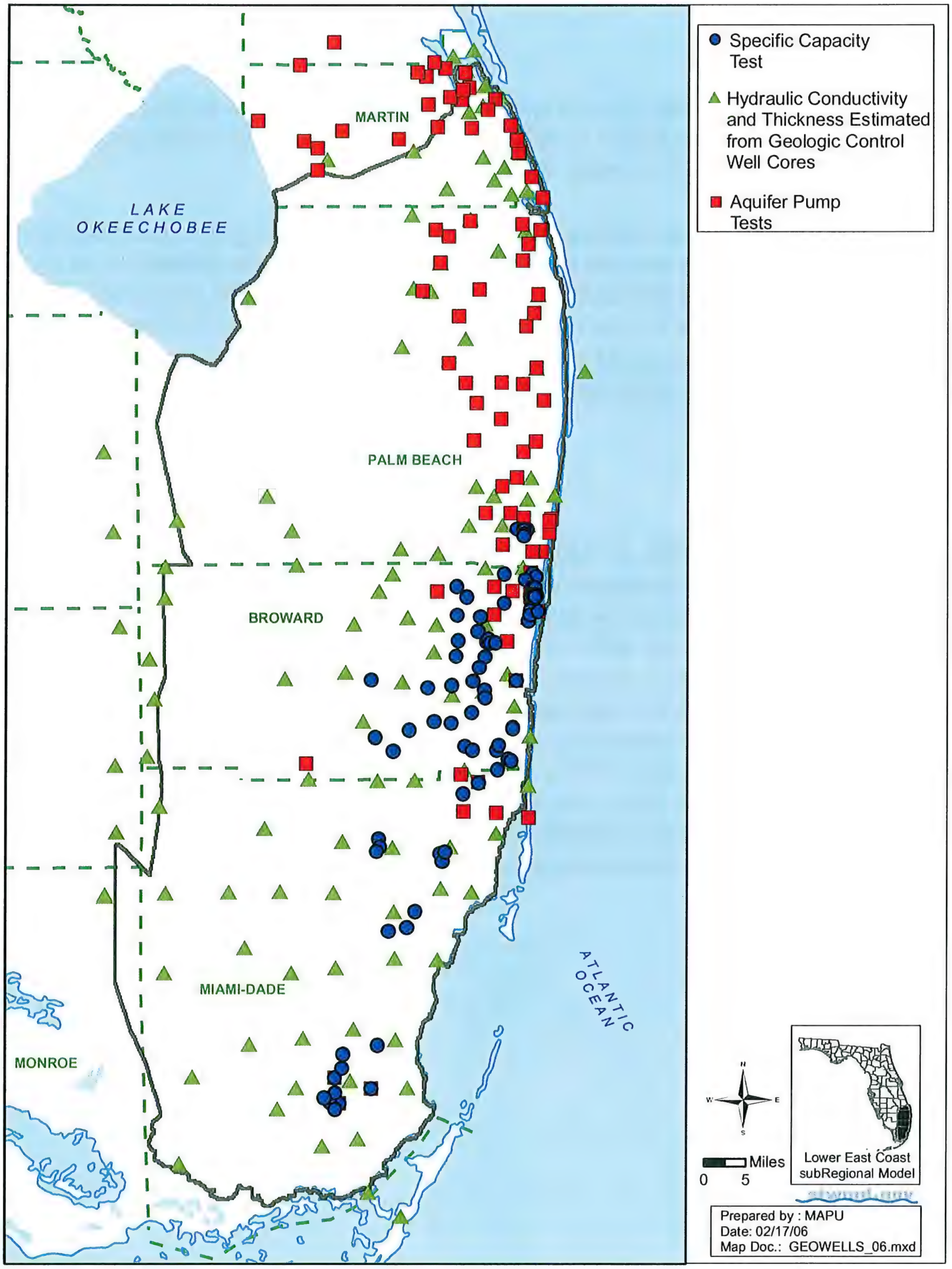


Figure 25. Locations of Control Points Used to Estimate Hydraulic Conductivity

The lack of APTs in Miami-Dade and Broward Counties in **Figure 28** is misleading. Fish and Stewart (1991) and Fish (1988) did a very detailed analysis of the hydraulic conductivity of the geologic control wells in those two counties. So the hydraulic conductivity for each section of each geologic control well has inherently incorporated into it the large number of APT's that have been conducted in south Florida over the years. Fish (1988) and Fish and Stewart (1991) used Causaras' (1985, 1987) detailed descriptions of continuous cores drilled in Miami-Dade and Broward Counties. Through a complex process, they determined hydraulic conductivity ranges continuously down each geologic control well. The information utilized in developing this data included geologic descriptions, lithology, previous APT's, new APT's, flow rates while drilling the test wells, hydrologic inferences from samples, sieve analysis, and the degree of sorting and grain size for clastic sediments (Fish and Stewart 1991). A similar process was utilized for the geologic control wells in Palm Beach and Martin Counties.

The geologic control wells allowed for a continuous profile of the hydraulic conductivity from ground surface to the base of the SAS. By overlaying our thickness maps for each of the five Q units and the members of the Tamiami Formation discussed in the Chronostratigraphy Section, estimated hydraulic conductivities for each unit were developed; they were based upon the weighted average for the hydraulic conductivities associated with that unit. This approach was used for every geologic control well in the study region.

Fish (1988) and Fish and Stewart (1991) also estimated the transmissivity of the production zones from specific capacity tests for a large number of municipal public water supply production wells in Miami-Dade and Broward Counties (**Figure 27**). Specific capacity tests are general short term pumping tests where only water levels in the production well are recorded for both drawdown and recovery. Utilizing the following empirical equation, they were able to estimate the transmissivity of the production zone for each well.

$$T = 270\frac{Q}{s}$$

Where T is the transmissivity, Q is the well discharge in gallons/minute, and s is the drawdown, in feet.

Hydraulic conductivities were determined from the screened or open-hole interval for each production well and by the unit(s) that it intercepted as determined from the chronostratigraphic maps. Since the production wells generally are screened across the main production zones of the aquifer, and the specific capacity tests were of short duration, it was assumed that the screened or open-hole interval was the main source of water and the transmissivity represented that zone of the aquifer. The hydraulic conductivity of the Chronostratigraphic unit(s) was then determined by dividing the transmissivity by the screened interval of the production well and a weighted average was then given to that unit(s).

APTs were used to help develop the geologic control wells in Palm Beach and Martin counties. In addition, they were used to provide point locations for the composite transmissivity of the aquifer as well as an estimate of the hydraulic conductivity of the production zone. Typical methods were used to analyze the results of the APT including Neuman, Hantush-Jacob, Boulton, and Cooper. In addition to providing transmissivity information, the APT's allowed for an estimation of the storativity of the aquifer. Storativity values general ranged between 2x10-1 to 5x10-5 with an average of approximately 1x10-3.

For the unconfined section of the aquifer, the specific yield needs to be known to ultimately be able to determine transient flow through the system. Merritt (1996) utilized rainfall and the corresponding rise in water levels in monitoring wells to estimate the porosity of the Miami Limestone. Short-term-duration rain events and predevelopment data were utilized to minimize the impact of runoff and rapid removal of water from secondary canal systems. It was determined that a specific yield of between 0.20 and 0.25 was reasonable for the Miami Limestone. Considering the similarities of the Miami Limestone with the other limestone units in the area, a specific yield of 0.2 for the entire SAS appears reasonable.

The vertical hydraulic conductivity is also a necessary component when evaluating flow through an aquifer system. The vertical hydraulic conductivity allows for movement vertically through the stratigraphic layers and is generally a fraction of the horizontal conductivity which is the preferred flow path. The vertical anisotropy ratio is the ratio of vertical to horizontal conductivity. Although numerous authors have estimated this ratio, the works of Geotrans (1986) and Langevin (2002) probably provide the best estimate of this ratio. Both of these works address movement of the salt water interface in south Florida in a three dimensional manner. The salt water interface in the study area is evaluated in a cross sectional manner and takes on an "S" curvature. The "S" curvature is where the toe of the saltwater interface is further inland than at the top of the aquifer. Geotrans (1986) reported that the degree of this "S" curvature is sensitive to the anisotropic ratio and suggested utilizing a ratio of 10:1. Langevin (2002) utilized a value of 100:1, but through sensitivity analysis reported no significant effect when this number is reduced.

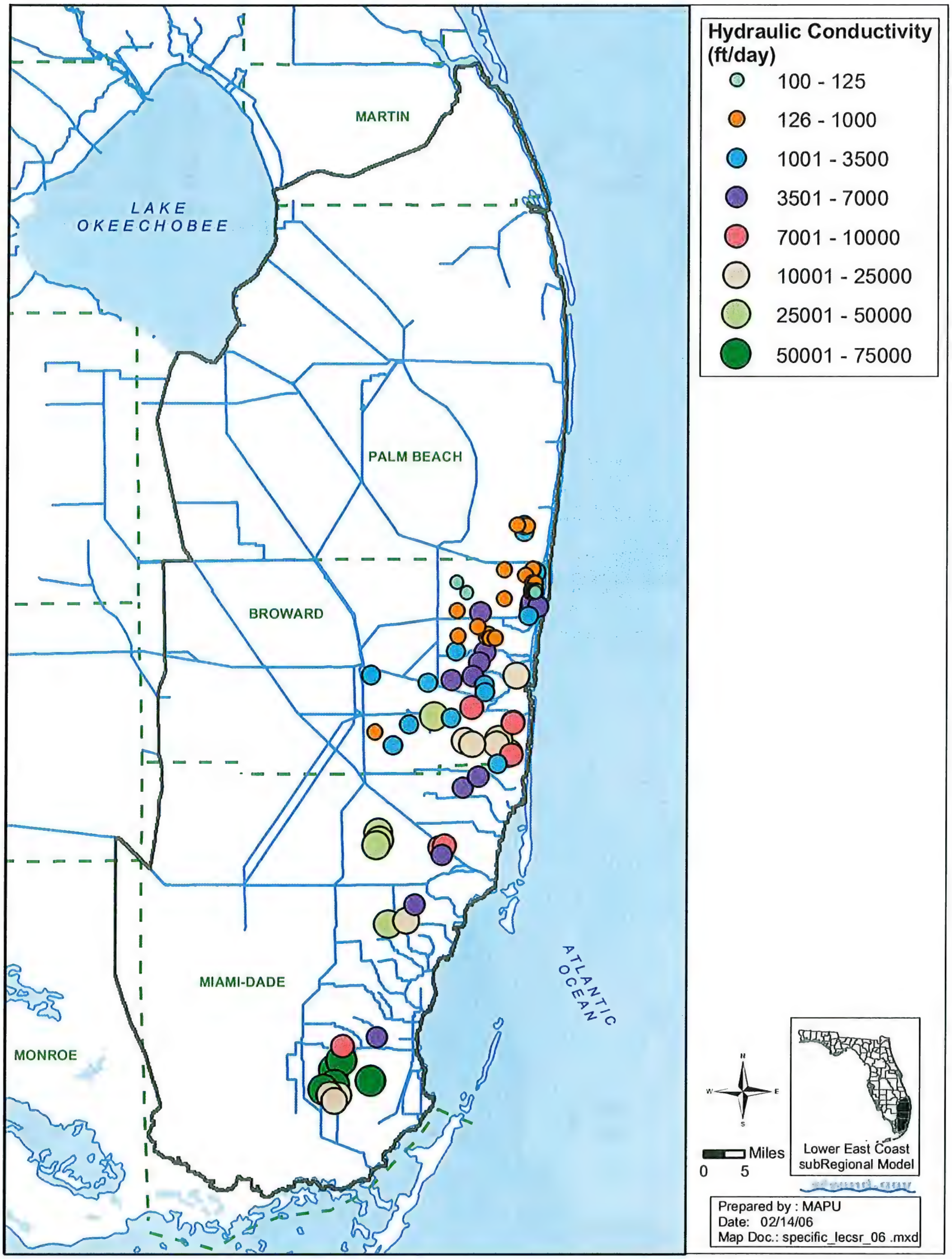


Figure 26. Horizontal Hydraulic Conductivity (ft/day) from Specific Capacity Tests.

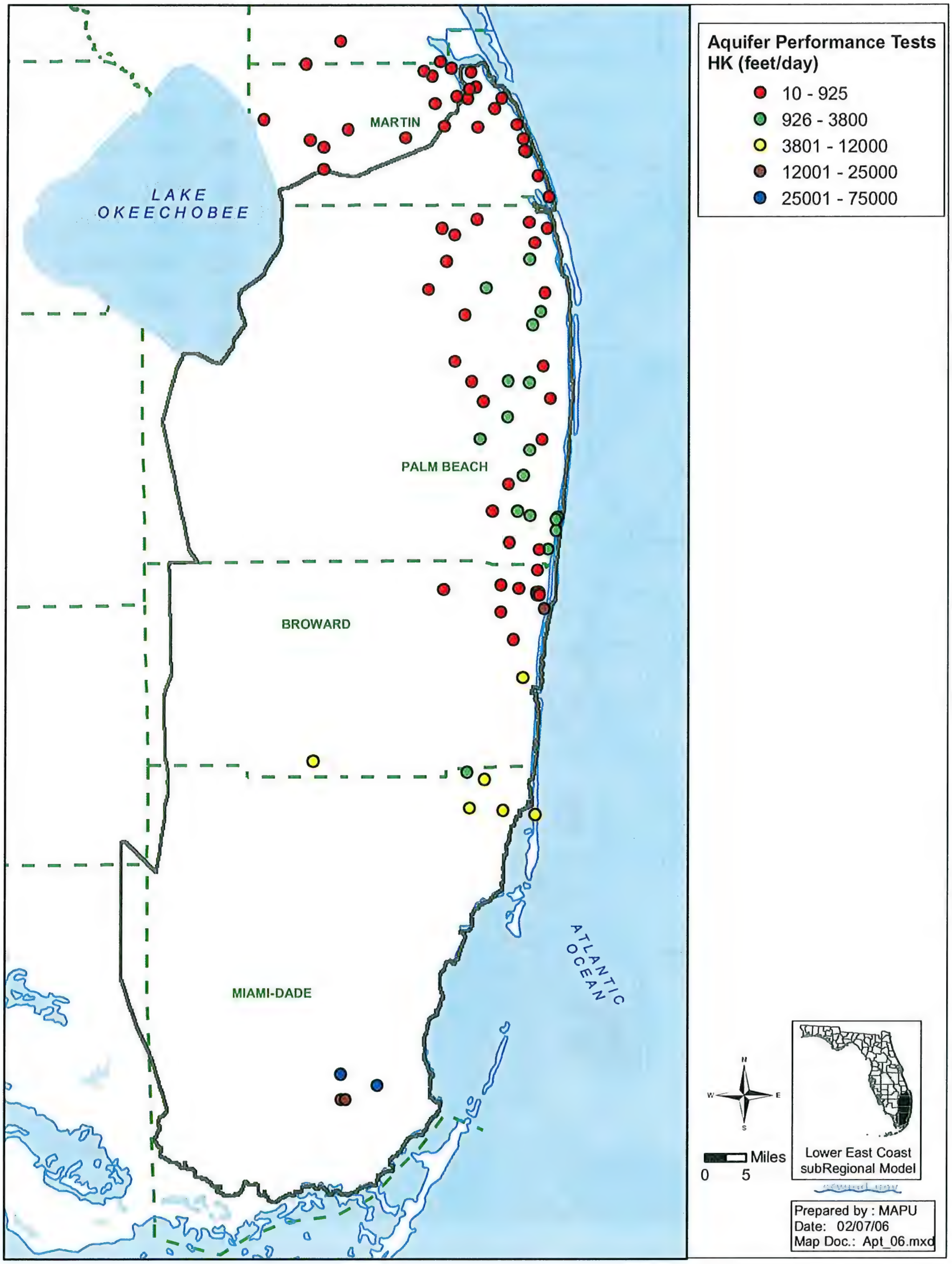


Figure 27. Horizontal Hydraulic Conductivity (ft/day) from Aquifer Performance Tests.

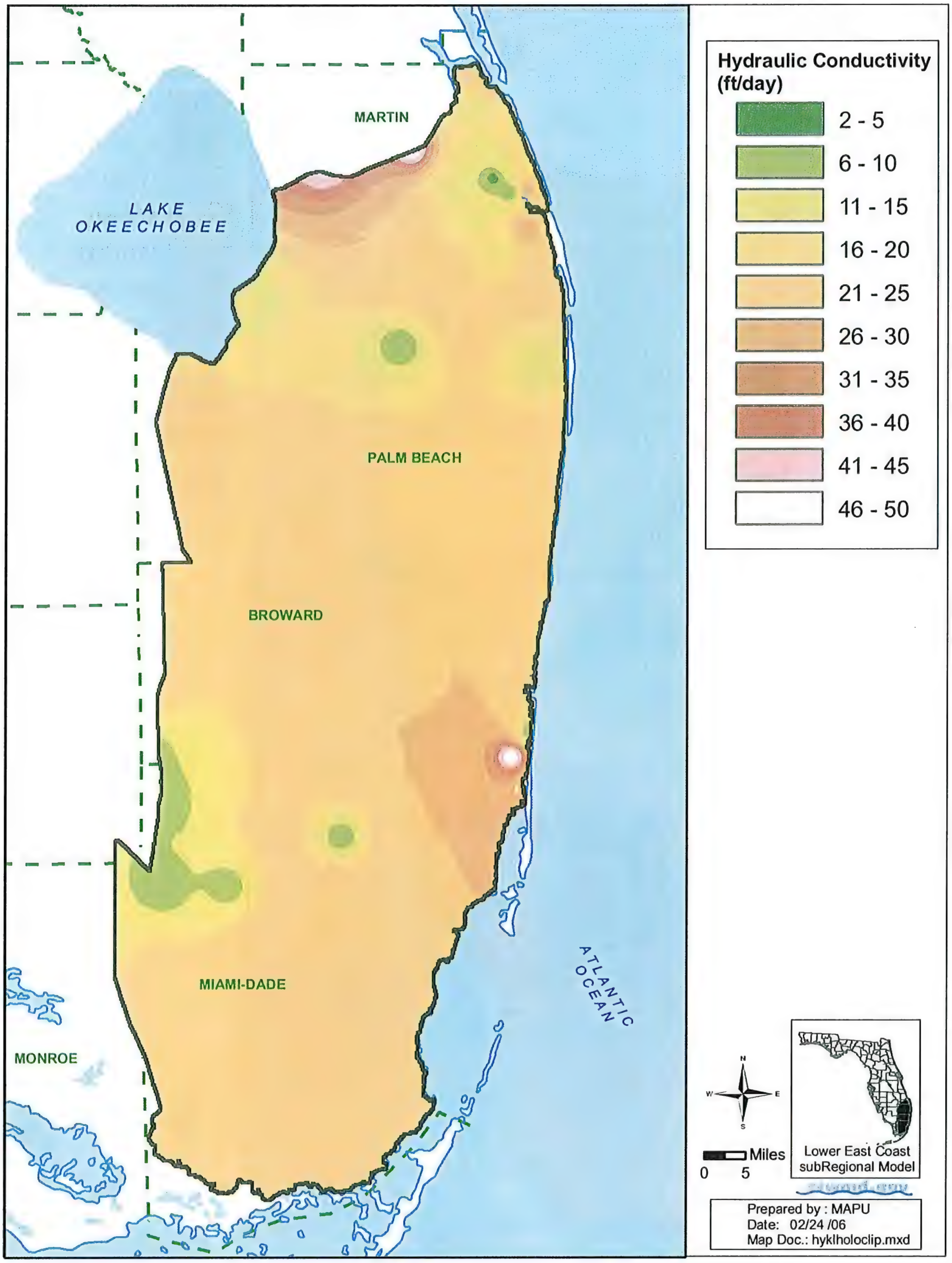


Figure 28. Horizontal Hydraulic Conductivity (ft/day) of the Holocene Sediments.

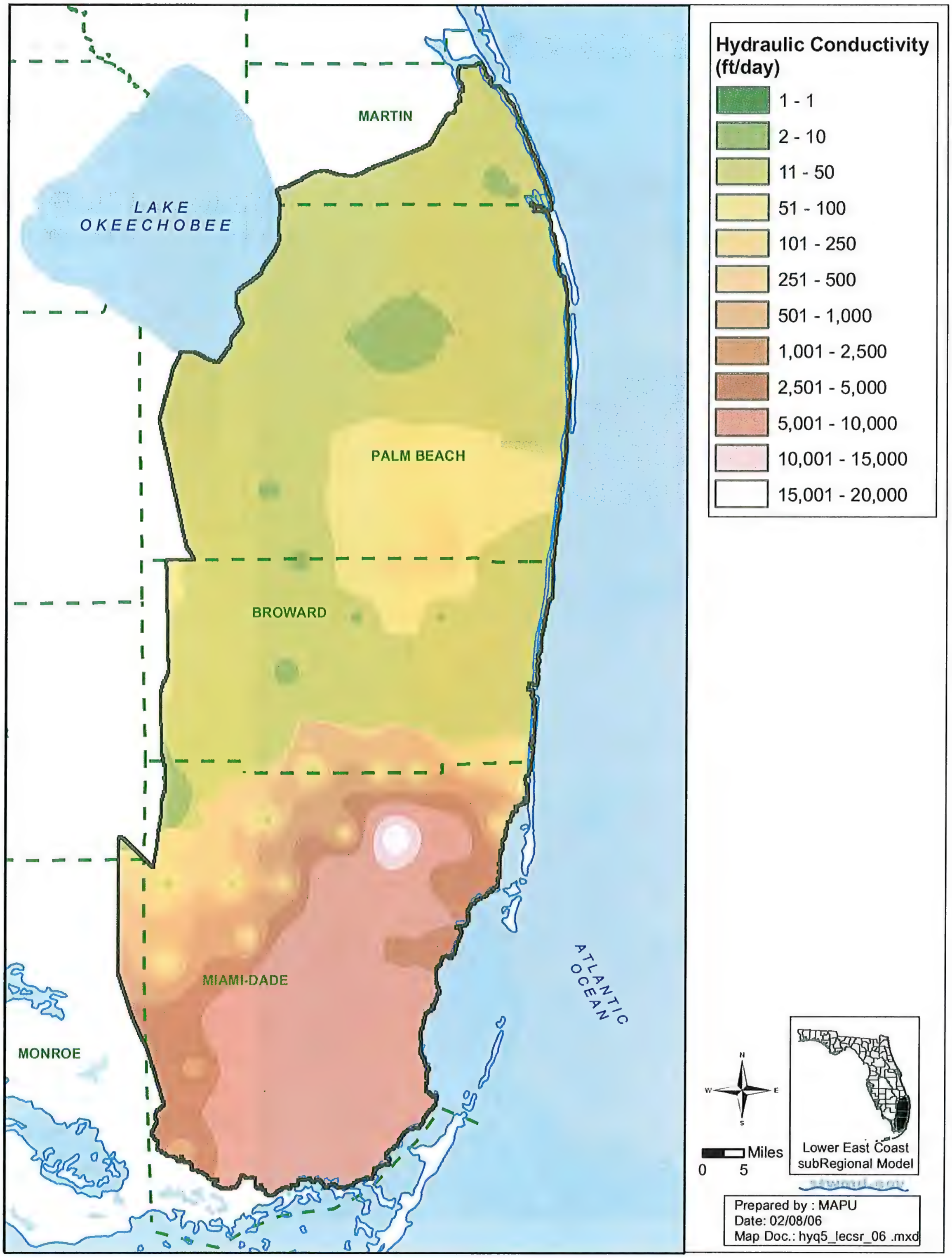


Figure 29. Horizontal Hydraulic Conductivity (ft/day) of the Q5 Unit.

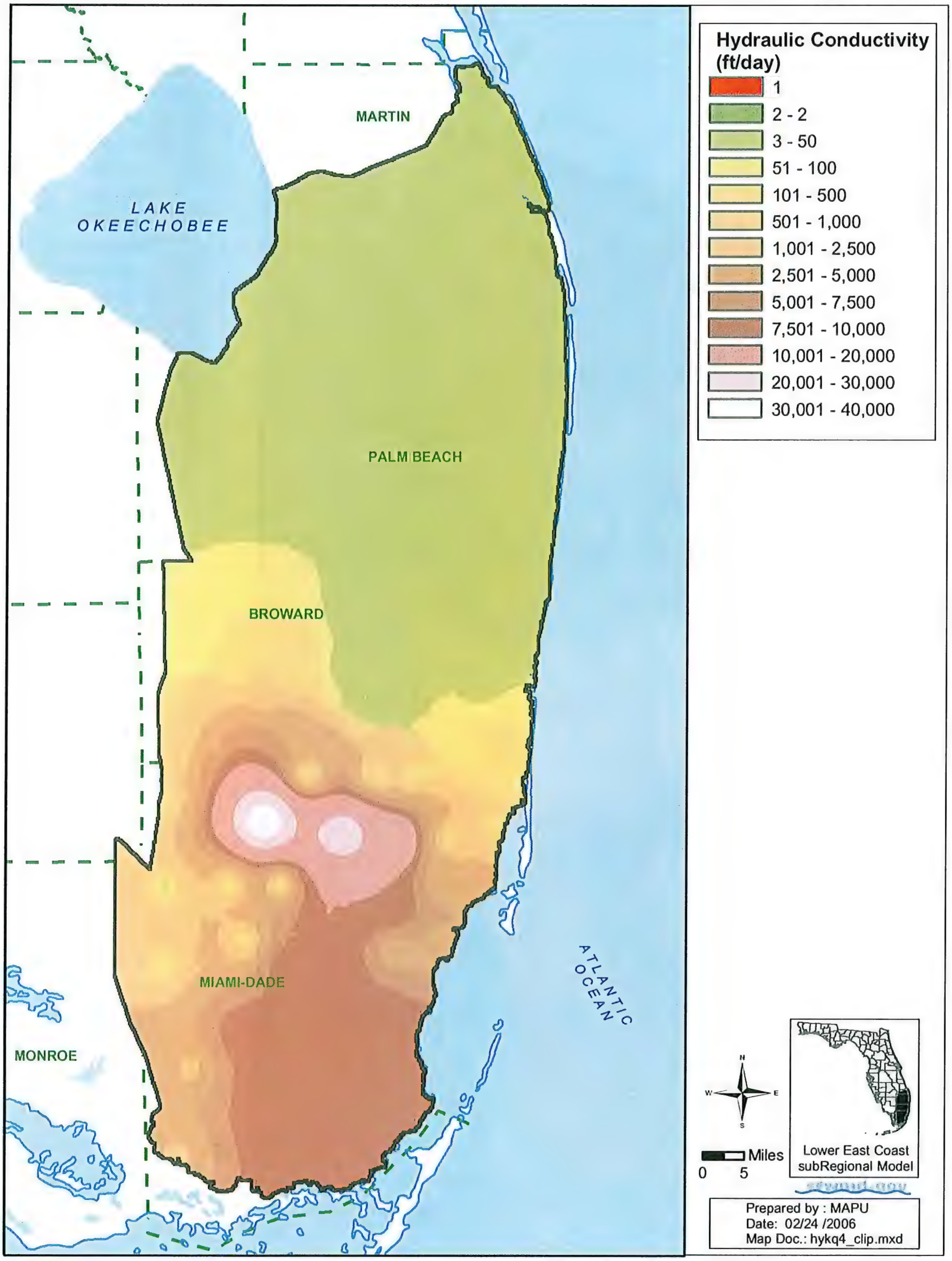


Figure 30. Horizontal Hydraulic Conductivity (ft/day) of Q4 Unit.

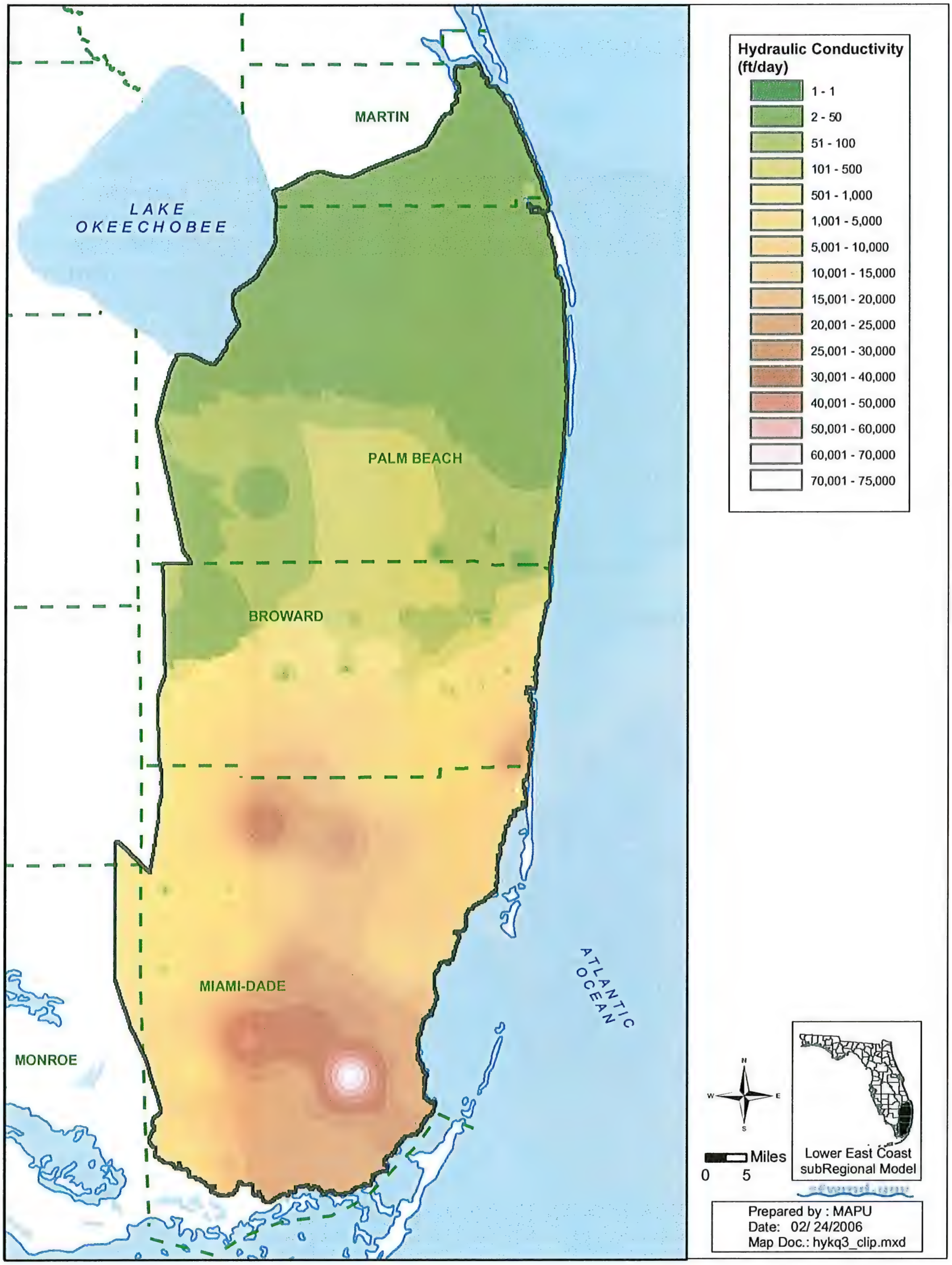


Figure 31. Horizontal Hydraulic Conductivity (ft/day) of Q3 Unit.

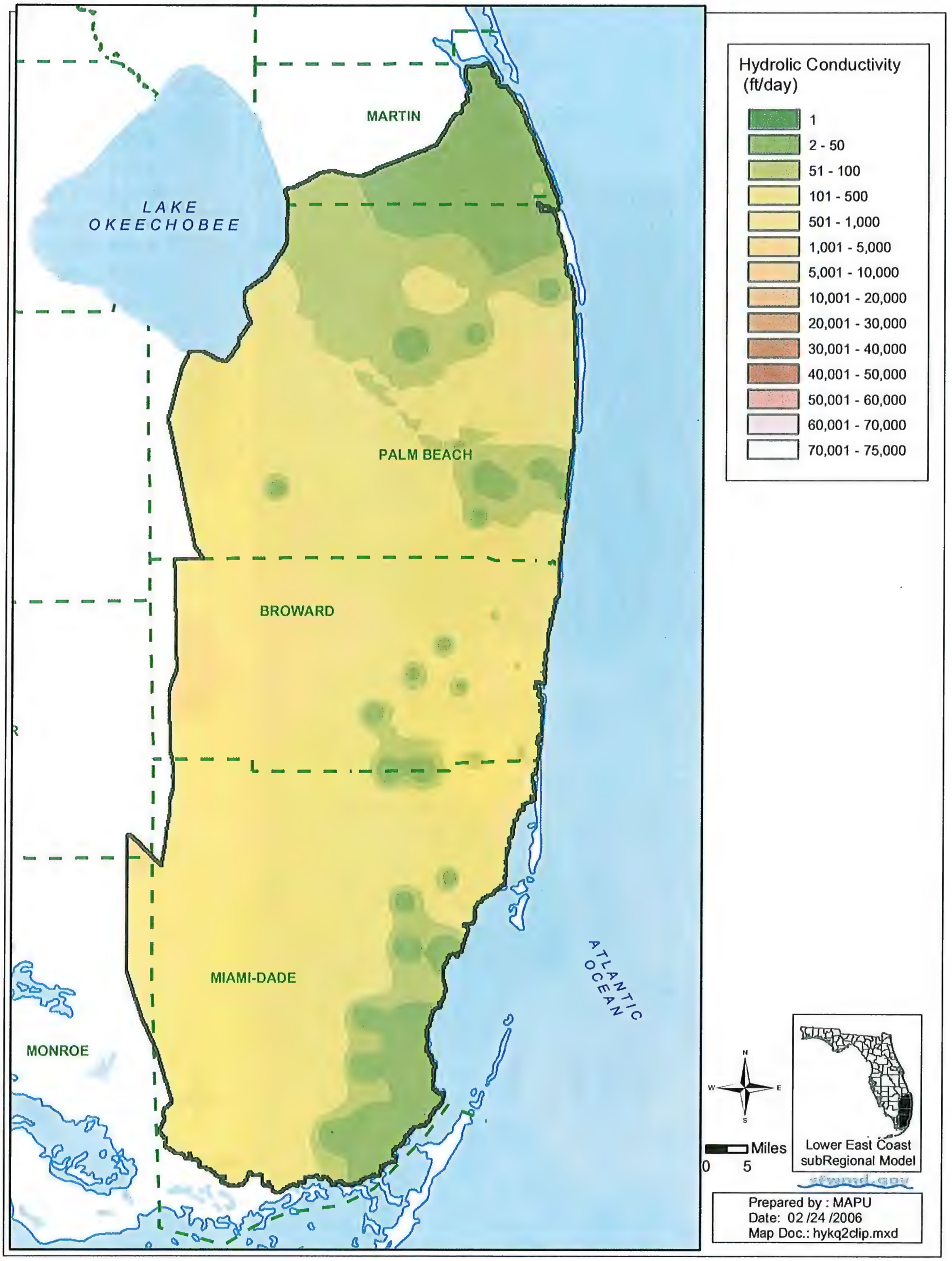


Figure 32. Horizontal Hydraulic Conductivity (ft/day) of Q2 Unit.

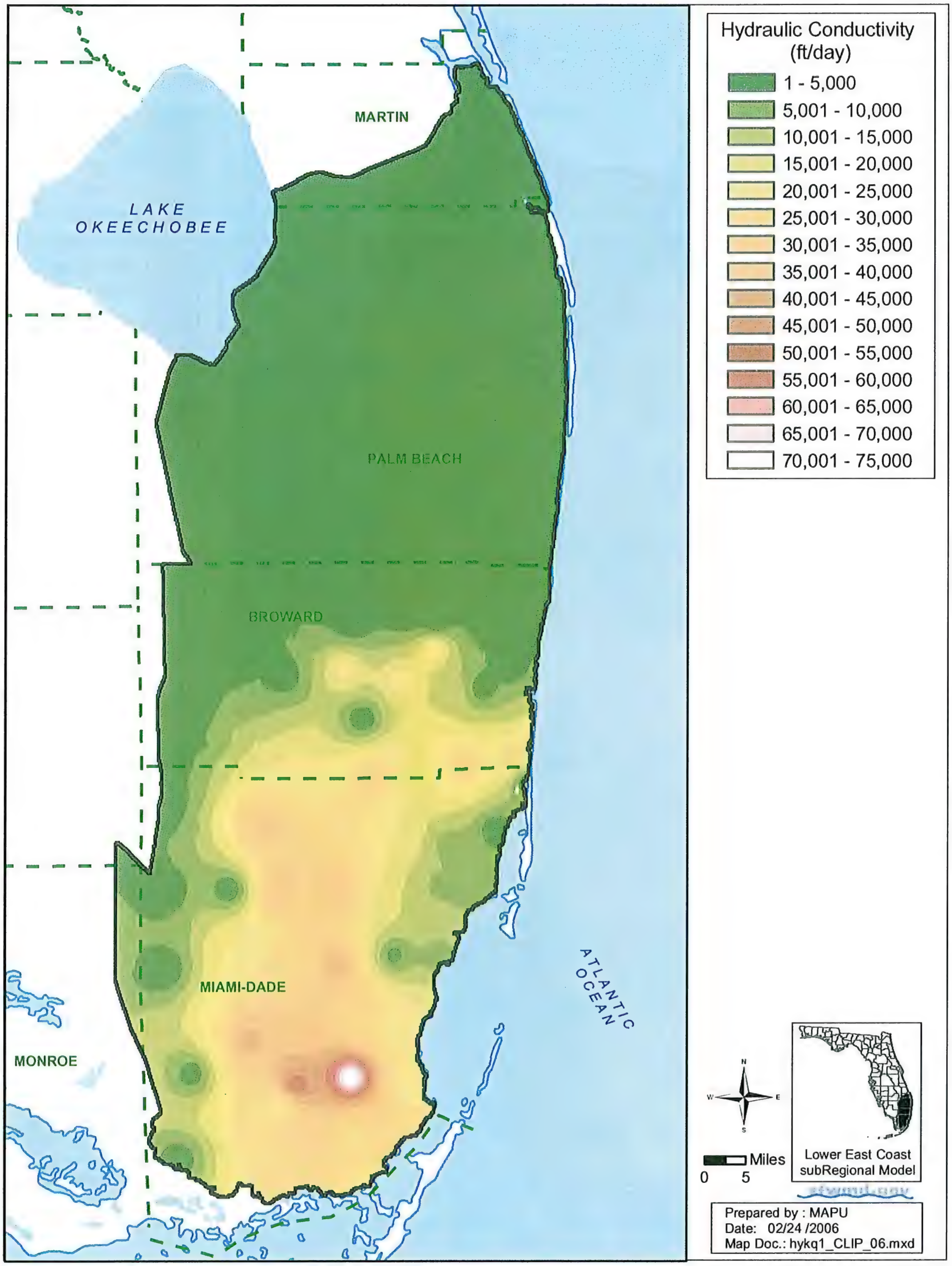


Figure 33. Horizontal Hydraulic Conductivity (ft/day) of Q1 Unit.

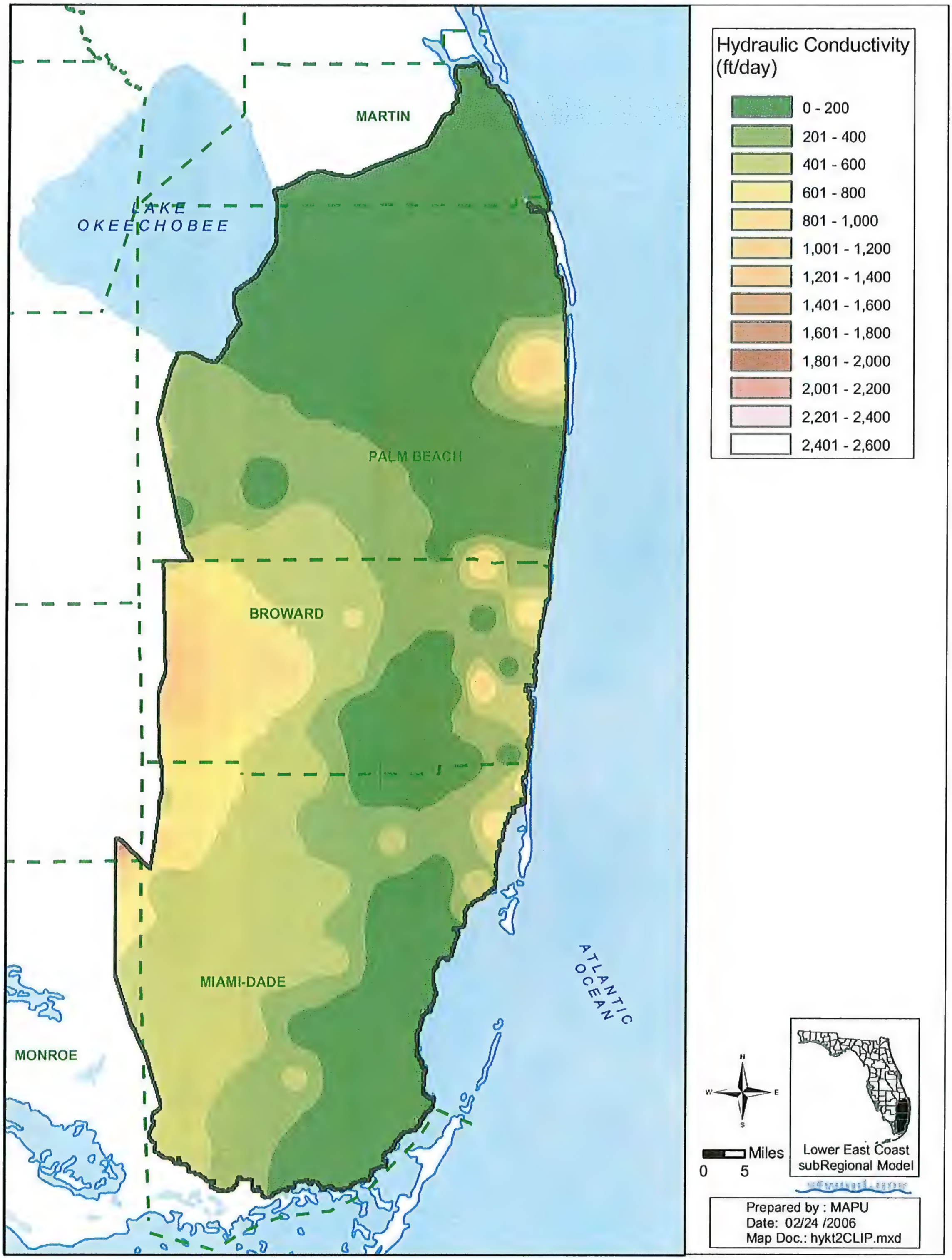


Figure 34. Horizontal Hydraulic Conductivity (ft/day) of the T2 Unit.

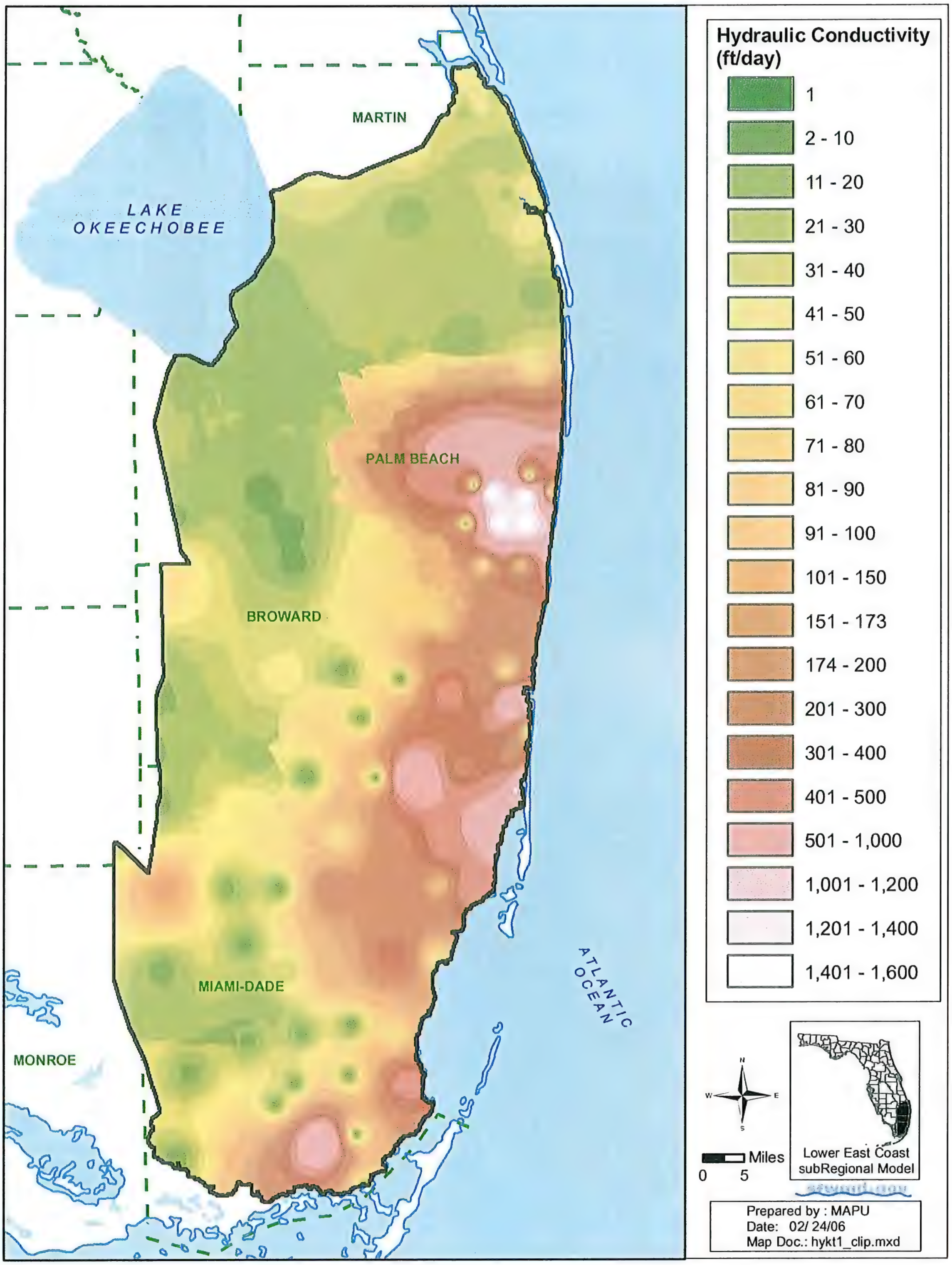


Figure 35. Horizontal Hydraulic Conductivity (ft/day) of the T1 Unit.

Saltwater Intrusion

A primary issue of concern for the Biscayne aquifer is contamination by a westward-moving saltwater front (SFWMD 2000). Several factors have contributed to the landward migration of the interface. Draining the Everglades and increasing wellfield pumping lowered the water table elevations and also increased peat and muck soil loss due to oxidation and compaction (Renken *et al.* 2005). As a result of extensive previous studies, the position of the current saltwater interface is a result of the following mechanisms: lateral landward movement when seawater moves from the Atlantic Ocean into the SAS, seepage from tidal canals containing saline water, and upconing when wellfield pumping causes relict seawater to move upward (Renken *et al.* 2005).

The 250 milligrams per liter (mg/L) saltwater intrusion line (**Figure 20**) at the base of the SAS is used in south Florida to evaluate potential saltwater contamination when wellfield withdrawals are increased. Additionally, the SFWMD has implemented minimum levels at several surface water structures to prevent landward migration of the saltwater front (SFWMD 2000).

One of the primary concerns associated with the Biscayne aquifer along the southeast coast of Florida is the threat of salt water intrusion. In order to minimize the threat of the inland migration of the saline interface, a sufficient fresh water head should be maintained landward of the saline interface. If a sufficient fresh water head is not maintained, then salt water intrusion can occur. Such was the case in 1939 when more than 10,000 water supply wells went salty in south Florida, including the partial loss of five major wellfields (Parker *et al.* 1955).

It is generally believed that one of the major reasons that salt water intrusion has historically occurred in south Florida is the loss of the fresh water mound behind the coastal ridge system (Parker *et al.* 1955; Fish and Stewart 1991). Prior to development, a large fresh water mound would develop behind the Atlantic Coastal ridge during the rainy season. Ground water flows would be so great seaward that springs would boil up off the coast providing freshwater to early mariners. As south Florida became developed, a series of canals and drainage ditches were constructed which drained this mound. The result was a significant decline in groundwater flow towards the ocean and, consequently, the inland migration of the saline interface. In addition to the canal network, large wellfields located adjacent to the coast have also been responsible for localized salt water intrusion problems.

In 1981, a severe drought in south Florida resulted in widespread movement of the saline interface. By 1987, the City of Hallandale had to permanently reduce pumpage by 50 percent and shut down their primary wellfield due to salt water intrusion (SFWMD 1987). Over the next couple of years, several golf courses in the Hollywood/Hallandale area were also required to curtail or eliminate groundwater withdrawals due to salt water intrusion. Koszalka (1994) reported that the saline interface continued to move inland in Broward County between 1980 and 1990 due to the lowering of regional groundwater levels and wellfield pumpage.

In the late 1800's, two scientists working independently observed that salt water was not found at sea level in an aquifer but at a specified depth depending upon the height of the fresh water in an aquifer. The depth to the salt water was approximately 40 times the height of the fresh water above sea level. They concluded that the distribution was attributed to a hydrostatic equilibrium existing between the two fluids of different densities (Todd, 1980). In general, they observed that for each 40 feet of aquifer thickness, a one foot fresh water head will need to be maintained to stabilize the salt water front under static conditions. The equation derived to explain their observations is referred to as the Ghyben-Herzberg relationship. The aquifer system along the southeast coast of Florida ranges in thickness from approximately 100 to 300 feet. Therefore, in order to ensure that salt water intrusion does not occur within these aquifer systems, freshwater heads of between 2.5 and 7.5 feet will need to be maintained based upon the Ghyben-Herzberg relationship.

Work done at Cutler Ridge in south Dade County indicates that the salt water front is not static as assumed by the Ghyben-Herzberg relationship (Kohout 1960). In addition, the observed position of the saline interface is several miles seaward of the position calculated using the Ghyben-Herzberg relationship. Kohout (1960) observed that as saltwater moved inland, a significant portion of the diluted sea water was circulated back toward the sea along the zone of diffusion. It is estimated that up to 20 percent of the salt water intruded into the aquifer is returned seawater with the remaining 80 percent being retained in the aquifer (Kohout 1960). This cyclic flow acts, in part, as a deterrent to salt water intrusion due to a percentage of the salt water being returned to the sea. It also indicates that salt water intrusion is dynamic and not static as assumed by the Ghyben-Herzberg relationship. However, Kohout's (1960) results suggest that the use of Ghyben-Herzberg levels to control the position of the salt water interface may be adequate because it tends to over predict the levels needed to maintain the position of the saline interface.

The City of Hallandale in southeastern Broward County, Florida has been an area susceptible to salt water intrusion for a number of years. A series of monitor wells located perpendicular to the coast have recorded the inland migration of the saline interface for over 35 years. Evaluation of the data suggests the saltwater front has consistently migrated inland at a rate of approximately 80 feet per year. Anderson *et al.* (1988) conducted a detailed evaluation of the salt water interface in the vicinity of Hallandale utilizing a coupled flow/solute transport three dimensional finite element model. They evaluated several potential causes for the continued intrusion including wellfield pumpage, rainfall deficiency and lowering of inland canal stages due to urbanization. Although their model could not localize the problem causing the salt water intrusion, the results clearly demonstrate the sensitivity of the saline interface to maintained ground water stages. Lowering the inland canal stages by even several tenths of a foot could result in widespread movement of the saline interface. In addition, Anderson *et al.* (1989), observed from their model simulations that a significant lag time existing between the lowering of hydraulic heads and the subsequent movement of the saline interface.

Because of these issues concerning movement of the saline interface, the SFWMD developed a series of Minimum Levels for the primary coastal canal structures based upon both analytical and numerical analysis (SFWMD 2000). Based upon the result of the analysis, it was recommended that canal stages at key coastal primary discharge structures be maintained a minimum level for a specific period of time during the year to begin to stabilize existing or future movement of the saline interface. **Table 3** is the recommended minimum canal operational levels for the Biscayne aquifer.

Table 3. Minimum Canal Operational Levels (ft NGVD) for the Biscayne Aquifer.

Canal/Structure	Wet Season Control Level	Average Canal Level	Drought Management Control Level	Minimum Canal Operational Levels to Avoid Violation[c]
C-51/S-155	8.50	8.12	7.80	7.80
C-16/S-41	8.20	8.23	7.80	7.80
C-15/S-40	8.20	8.39	7.80	7.80
Hillsboro/G-56	7.70	7.43	6.75	6.75
C-14/S-37	7.20	6.82	6.50	6.50
C-13/S-36	5.60	4.43	4.00[b]	3.80
NNR/G-54	4.00	3.68	3.50	3.50
C-9/S-29	3.00	2.16	1.80	2.00
C-6/S-26	4.40	2.55	2.50[b]	2.00
C-4/S-25B	4.40	2.55	2.50[b]	2.20
C-2/S-22	3.50	2.86	2.50[b]	2.20

a. Duration Criterion – water levels within the above canals may fall below the proposed minimum canal level for a period of no more than 180 days per year.

b. These levels will be maintained if sufficient water is available.

c. Minimum Canal Operational Levels needed to protect against MFL violations during drought conditions.

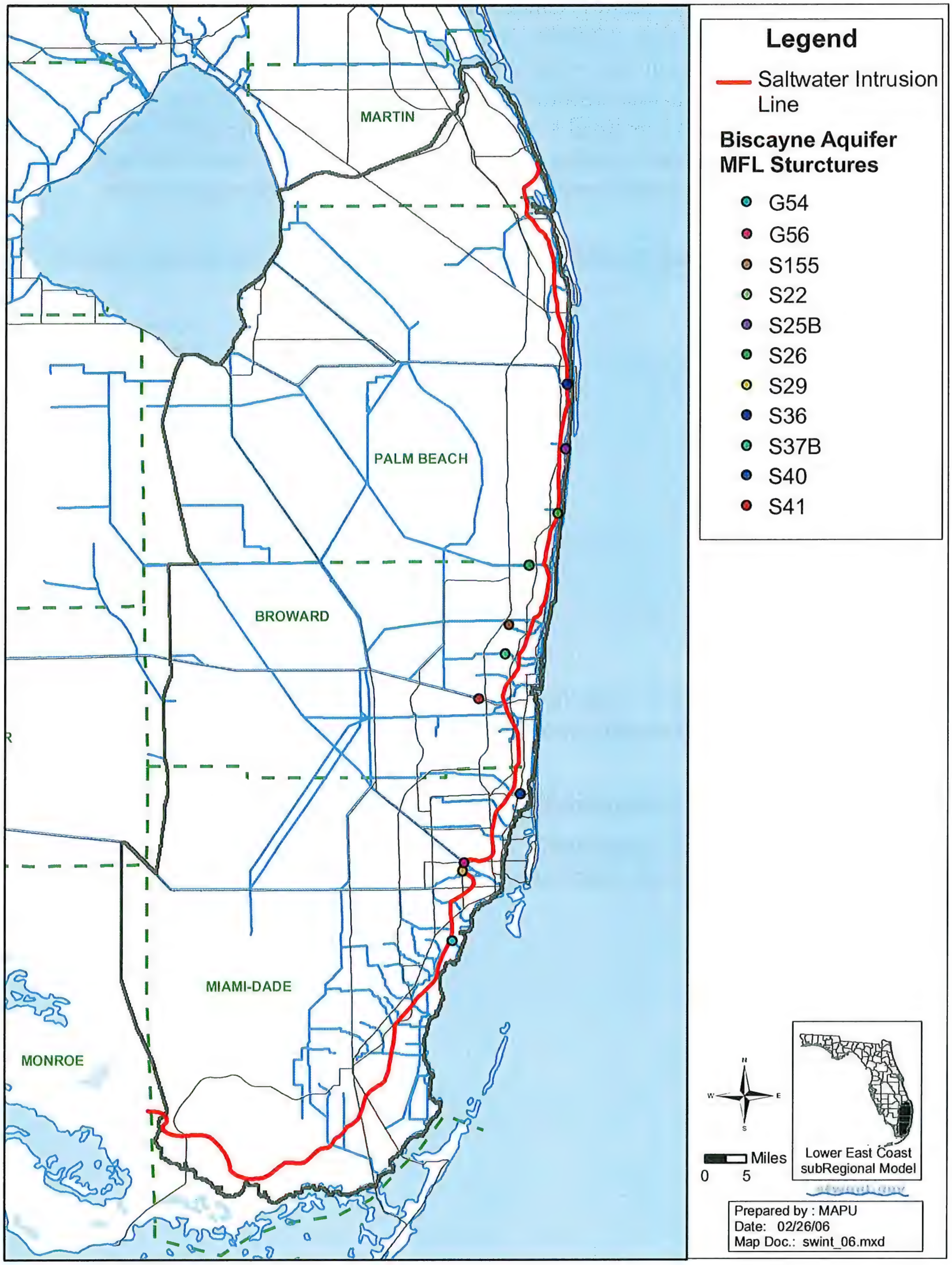


Figure 36. Location of the Saltwater Interface. Source: After Renken *et al.* 2005

WATER USE

Within the study area, ground-water and surface-water withdrawals for public water supply, industrial (including power plants), landscaping and agricultural uses were estimated from the South Florida Water Management District permit data base. In Miami-Dade, Broward, Palm Beach and Martin counties there are approximately 7,000 water use permits issued with a total daily permitted demand of approximately 3.2 billion gallons per day in the year 2004. The main agricultural users of surface water are the citrus groves in the northern portion of the study area and the Everglades Agricultural Area. The public water supply systems in the study primarily use the Surficial Aquifer System with the exception of some Floridan aquifer use in the northern portion of the study area. Surface water as a public water supply source is restricted to the small communities surrounding Lake Okeechobee and the City of West Palm Beach.

Of the top five largest permitted users of water in the study area, three are for Public Water Supply, including Miami-Dade Water and Sewer Department and Palm Beach County Water Utilities Department, while the other two are for diversion of surface water from the regional system into secondary canal systems and include the Lake Worth Drainage District located in central and southern Palm Beach County and Old Plantation Water Control District in central Broward County. These diversion permits accomplish multiple uses including re-hydration of urban wetland systems, provide water for agricultural and landscaping purposes, and maintain the vast system of secondary canals to recharge local wellfields and help prevent saltwater intrusion.

The two largest use classes of water in the region are agriculture and public water supply, which account for approximately two-thirds of the entire demand. The main industrial use is primarily associated with limestone rock mining. Palm Beach County has the greatest amount of permitted water use in the region with over 1 billion gallons per day permitted. Domestic self-supplied use is not included in the analysis because, with the exception of some rural areas, the majority of the population is supplied from a public water supply system. The main domestic use is through irrigation of home-site landscaping with private wells, which even then is prohibited in some communities.

Table 4. Permitted Water Use in South Florida, Expressed in Million Gallons Per Day (MGD).

	Broward	Miami Dade	Palm Beach	Martin	Totals
Agriculture	23.8	36.8	761.8	211.8	1034.2
Dewatering	76.4	76.4	274.5	18.4	426.5
Diversion	96.2	0.0	189.6	0.0	285.8
Golf Course	18.6	10.3	48.1	8.7	85.7
Industrial	4.3	99.6	32.2	8.0	144.1

Landscaping and Nursery	37.2	18.0	47.1	8.4	110.7
Public Water Supply	282.8	497.2	290.7	27.2	1097.9
Totals	539.3	719.1	1644.0	282.5	3184.9

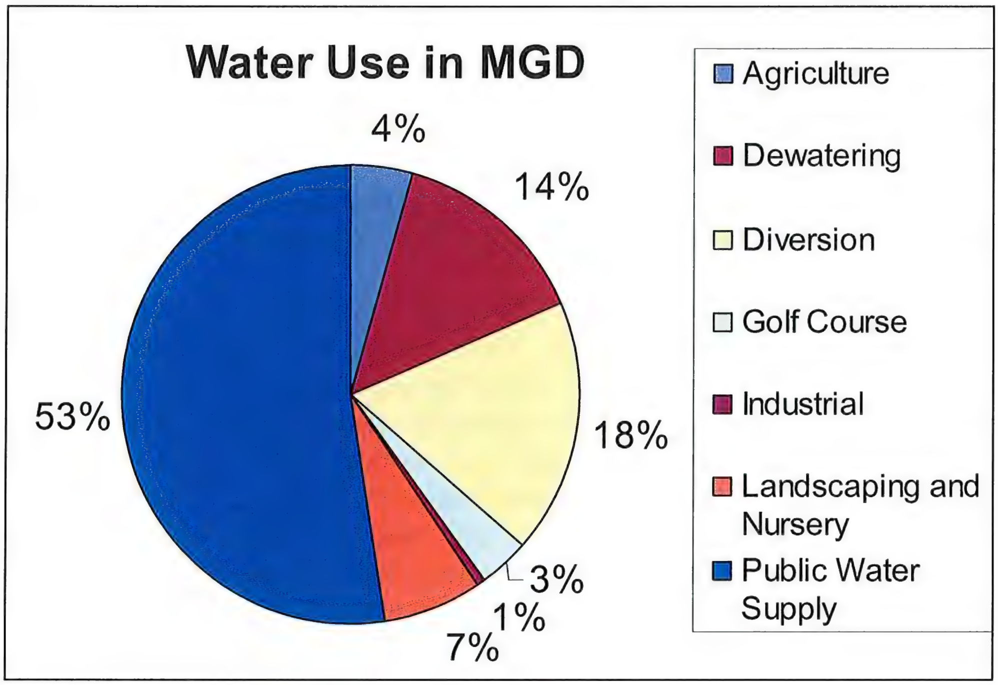


Figure 37. Water Use by Class in 1994.

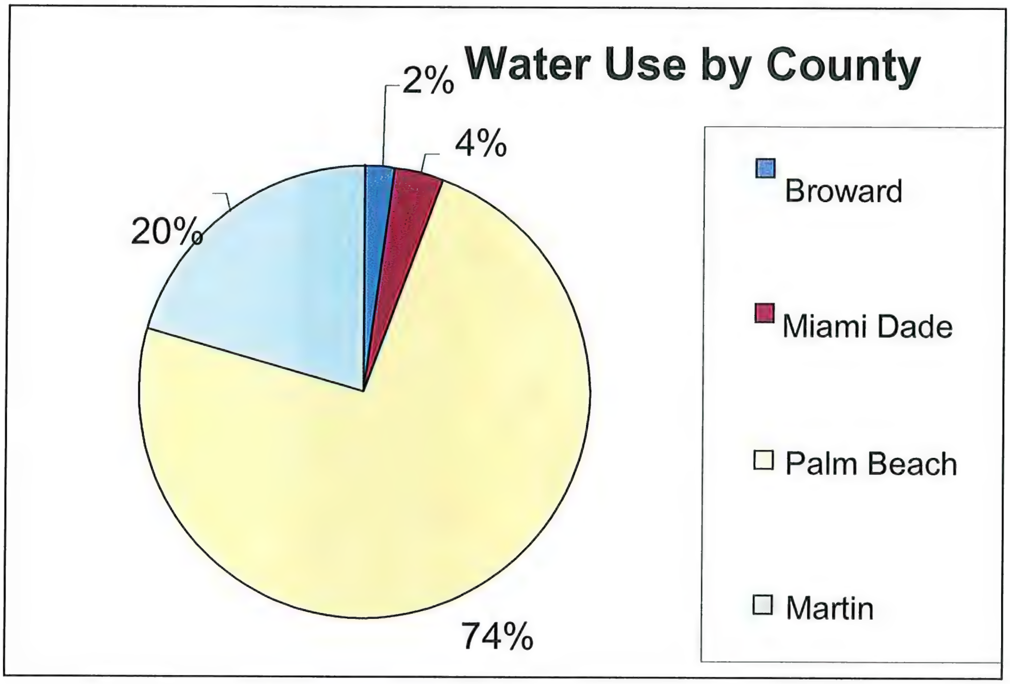


Figure 38. Water Use by County in 1994.

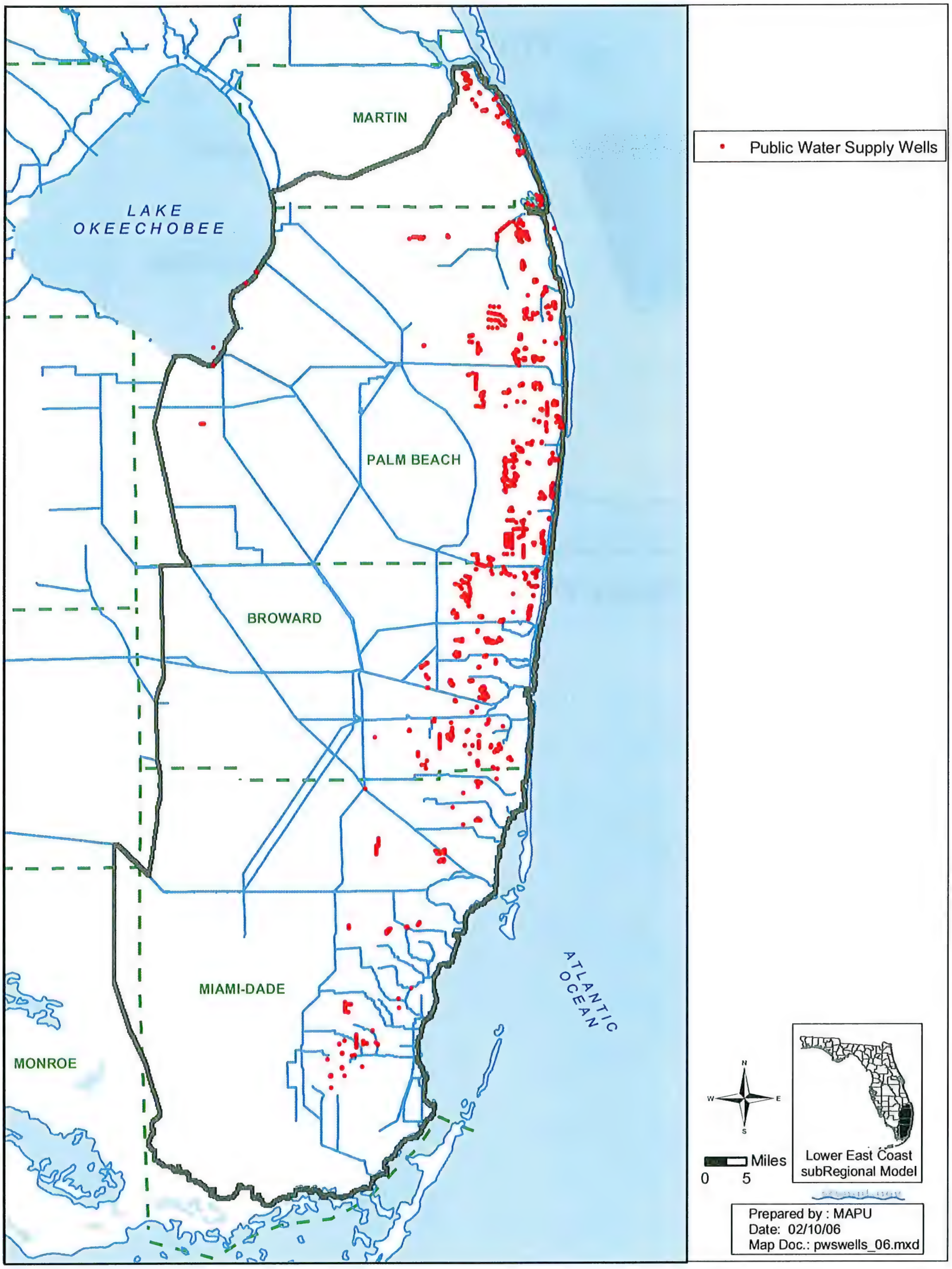


Figure 39. Public Water Supply Wells in Southeast Florida.

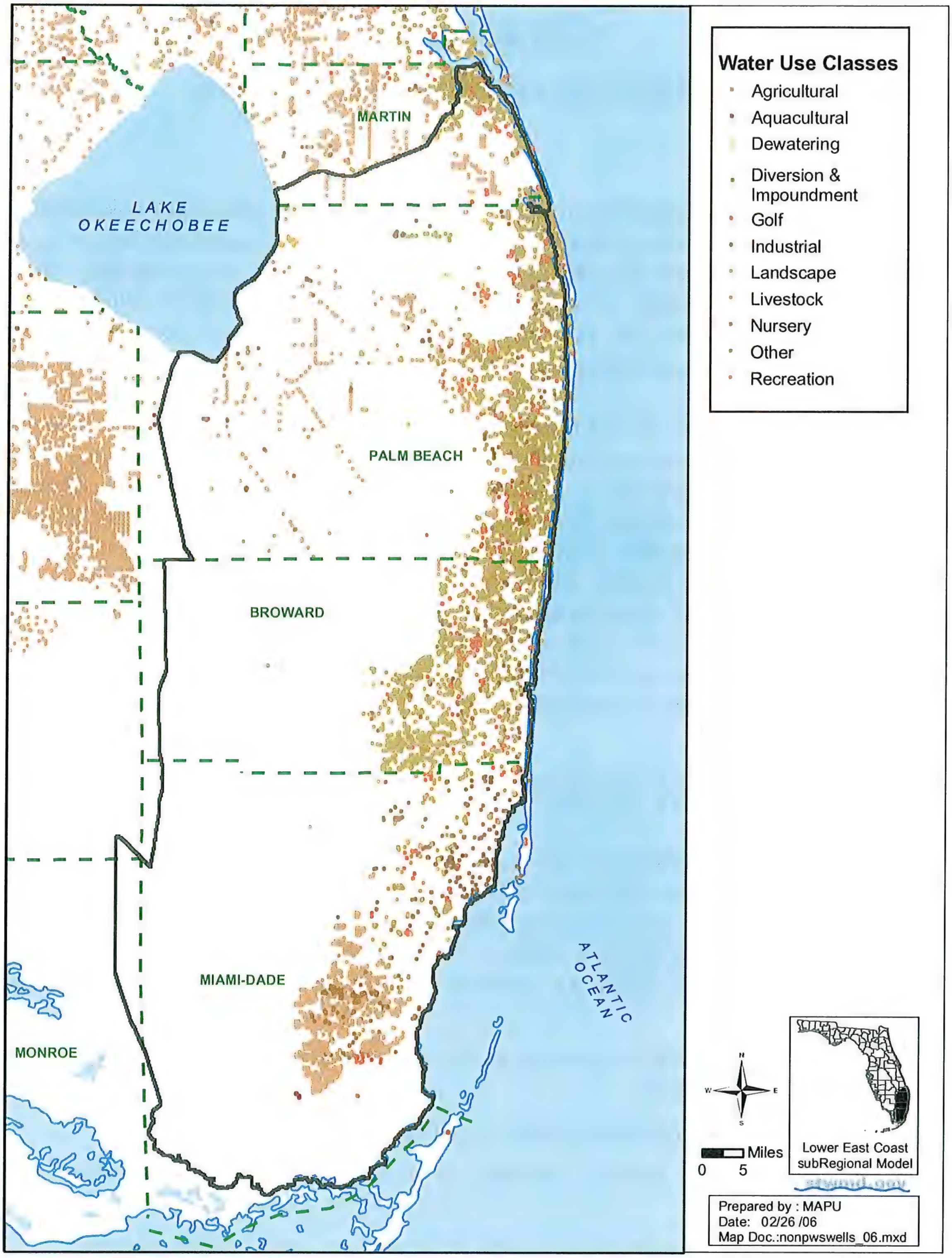


Figure 40. Consumptive Use Locations Other than Public Water Supply Categorized by Type of Use in Southeast Florida.

CHAPTER 3
Simulation of the Flow System

The process of model design for the LECsR truly began with the first subregional groundwater models at the SFWMD in the early 1990's. As stated in Chapter 1, the knowledge base in south Florida is growing and there are many research efforts contributing to this wealth of knowledge. Development of LECsR relied on the knowledge gained from the previous subregional models and experienced staff throughout the SFWMD, as well as the most current, best available data.

Model design for the LECsR Model has been an iterative process. The first version of this model was initiated three years ago and resulted in a calibrated model which was further refined due to a request by management to extend the calibration period by ten years. During this time, the model evolved by incorporating new data and modeling capabilities within MODFLOW-96. These events required revisiting the modeling protocol. It is through this iterative process of re-formulating the conceptual model, re-designing and re-calibrating that has produced the current version of the LECsR Model. In the future, the model will evolve and mature using this iterative process as needed to keep up to date with the best available data without invalidating the peer review (i.e., a step-wise post-audit).

COMPUTER CODE SELECTION

Once modeling objectives have been established and the predominant hydrologic processes within the area of interest have been determined, a model code that can meet the model development and application objectives is selected. MODFLOW-96, a code created by the U.S. Geological Survey (USGS) (Harbaugh and McDonald 1996; McDonald and Harbaugh 1988), was selected for this purpose for the following primary reasons:

- It has been widely accepted in the groundwater modeling profession for over 20 years.
- The code is well documented and within the public domain.
- The code is readily adaptable to a variety of groundwater flow systems.
- The code is modular and easily facilitates any modifications required to enable its application to the types of unique groundwater flow problems encountered in south Florida.
- MODFLOW was used to develop existing groundwater flow models located within the LEC that could be upgraded to meet the current objectives.

- In the future, MODFLOW models may be updated to the variable density (with solute transport) transient flow model, SEAWAT (Langevin *et al.* 2003), which is fully compatible with MODFLOW.

MODFLOW with District Source Code

MODFLOW simulates groundwater flow in aquifer systems using the finite-difference method. The aquifer system is divided into rectangular or quasi-rectangular blocks by a grid (**Figure 41**). The grid of blocks is organized by rows, columns, and layers, and each block is commonly called a cell.

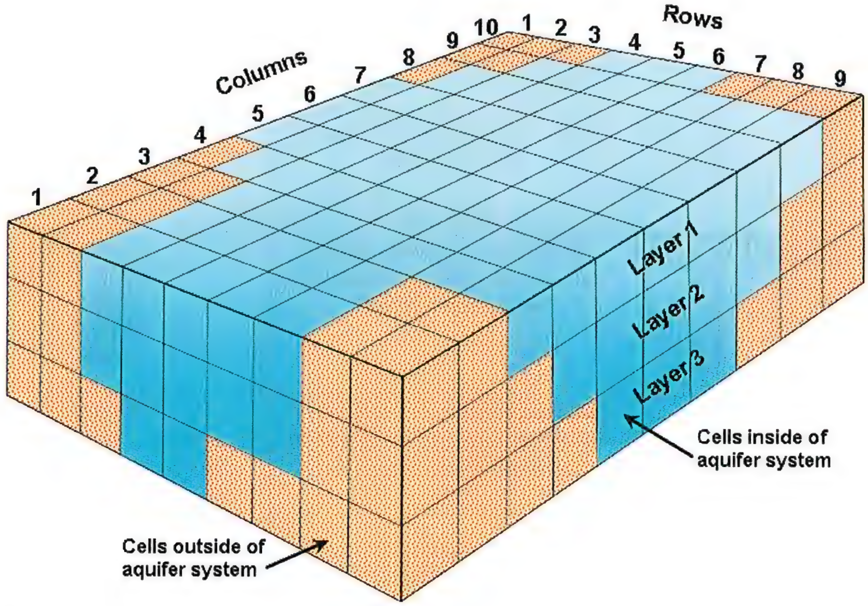


Figure 41. Example of Model Grid for Simulating Three-Dimensional Groundwater Flow.

For each cell within the aquifer system, the user must specify aquifer properties. Also, the user specifies information relating to wells, canals, and other hydrologic features for the cells corresponding to the locations of the features. For example, if the interaction between a canal and an aquifer system is simulated, then for each cell traversed by the canal, the required input information includes layer, row, and column indices; canal stage; and hydraulic properties of the channel bed. Also, MODFLOW allows the user to specify which cells within the grid are part of the groundwater flow system and which cells are inactive (i.e., outside of the groundwater flow system).

The MODFLOW model code consists of a main program and a series of independent subroutines called modules. The modules, in turn, have been grouped into packages which each deal with a particular hydrologic process or solution algorithm. The packages used for the LECsR Model development and application, including those developed or enhanced by SFWMD staff and contractors, are shown in **Table 5**. The enhanced packages have been added to the MODFLOW-96 computer source code over the last decade. Therefore, the SFWMD has not migrated to MODFLOW-00, but intends

to do so in the near future. The planned migration will include updating MODFLOW-2000/SEAWAT-2000 with the add-on (or enhanced) packages.

Table 5. MODFLOW Packages Used in the LECsR Model.

Package	Description	Notes
	Core	
Basic and Output Control (BAS and OC)	Defines stress periods, time steps, starting heads, grid specifications, units, and output specifications.	Handles the primary administrative tasks associated with a simulation.
Block-Centered Flow (BCF)	Specifies steady state vs. transient flag, cell sizes, anisotropy, layer types, and hydrogeologic data for each layer.	Derived primarily from geologic data used to construct the model.
Utility Generation (UGEN)	Creates input files during model execution by linking static (time invariant) data with time series (variant) data.	Generates input for Well, General Head Boundary, Diversion, River, Reinjection Drainflow, and Drain Packages.
	Surface Water Stresses and Processes	
Recharge (RCH)	Simulates aerially distributed recharge to a water table during each stress period.	Preprocessed using an Agricultural Field-Scale Irrigation Requirements Simulation (AFSIRS) based ET- Recharge model.
Evapotranspiration (EVT)	Simulates removal of water from the water table via transpiration and direct evaporation.	Preprocessed using an AFSIRS based ET-Recharge model; Saturated ET rate diminishes with increasing water table depth.
River (RIV)	Simulates groundwater interchanges with canals that can either recharge or drain the aquifer.	Canal stages are usually based on measured stages or control elevations.
Drain (DRN)	Essentially the same as the River package except that canals can only drain the aquifer and water removed by the drains is removed permanently from the model.	Canal stages are usually based on weir elevations and topography.
Diversion (DIV)	Simulates the effects of water control structures (either pumping stations or gravity flow drains) on water levels.	Allows simulation of operational rules at structures and diversion of water, including external sources like locks and external sinks like the ocean.
Reinjection Drainflow (RDF)	Essentially the same as the Drain package except that it allows water to be redirected to another location in the model instead of being permanently removed from the model.	Allows simulation of seepage control systems where water is diverted out of the seepage canal based on a control level.
Horizontal Flow Barrier (HFB)	Simulates thin vertical barriers to horizontal flow.	Used for slurry walls.
Wetland (WTL)	Simulates the overland flow in wetlands using the uppermost	Enhanced to also simulate barriers to flow like levees.

	model layer.	
General Head Boundary (GHB)	Simulates groundwater exchange between selected cells and a specified boundary as a function of water level difference.	Boundary stages are usually based on measured stages.
Water Supply and Management		
Well/Multiple Wells (WEL)	Simulates withdrawals from wells. Enhanced by the District to read multiple input files	Includes Public Water Supply (PWS), irrigation, and Aquifer Storage and Recovery (ASR) wells.
Trigger (TRG)	Simulates wellfield withdrawal cutbacks as a function of water level in trigger cells and in Lake Okeechobee; simulates LEC water shortage policy associated with saltwater intrusion	Cutback zones are based on calibration of model to historical water shortages including the historical Lake Okeechobee cutbacks.
Solution Algorithms		
Strongly Implicit Procedure (SIP)	A mathematical solution algorithm internal to the model	Enhanced by District to improve model stability by allowing maximum iterations to be exceeded and the closure criteria to be loosened for a short number of stress periods.
Preconditioned Conjugate Gradient (PCG)	A mathematical solution algorithm internal to the model	PCG2 uses the preconditioned conjugate-gradient method to solve the equations produced by the model for hydraulic head.
Output Management		
Output Control Summation (OC)	Sums cell-by-cell flows to reduce output size	Set up in the output control.
Multibud (BUD)	Outputs an internal water budget for a set of specified cells at a given frequency to reduce output size.	Frequency of flow output is user-specified (e.g., daily or monthly).

Add-On District Packages

The modular structure of MODFLOW readily allows for modifications or the creation of additional packages. The SFWMD has taken advantage of this feature and developed several additional packages and made enhancements to the original MODFLOW-96 code which are described in this section. Additional information about these packages may be obtained by contacting the SFWMD.

Wetland Package

The Wetland (WTL) Package was developed by the SFWMD and the Center for Hydrology and Water Resources at Florida Atlantic University (FAU) (Restrepo *et al.* 1998). The current version has been revised and improved by FAU in association with the SFWMD, as the package has been applied to subregional models in south Florida, to

fulfill the need for a sound, physical-based representation of wetlands and surface water-groundwater interaction.

Prior to the development of the Wetland Package used in this model, wetlands were often simulated as constant head or general head boundaries in groundwater models (Merritt 1995). These approaches have limitations, especially with the periodic drying and rewetting of wetland cells that occur when water levels fluctuate below and above land surface (Wilsnack *et al.* 2001).

The Wetland Package is incorporated into the MODFLOW groundwater model code (Harbaugh and McDonald 1996) and enables the top layer of the grid system to contain overland or groundwater flow. The wetland module can account for vegetation characteristics, simulation of sheet flow, sloughs, levees, and barriers, and evapotranspiration as shown in **Figure 42**. This figure also illustrates the interaction between the channel flow (e.g., slough) and aquifer and between sheet flow and the aquifer. In the model, the top layer can include sheet flow together with aquifer and the muck/peat layer. This add-on package makes it possible to simulate the areal expansion and contraction of wetland systems and the associated water routing (horizontal and vertical) in response to different hydrologic conditions (Restrepo *et al.* 1998).

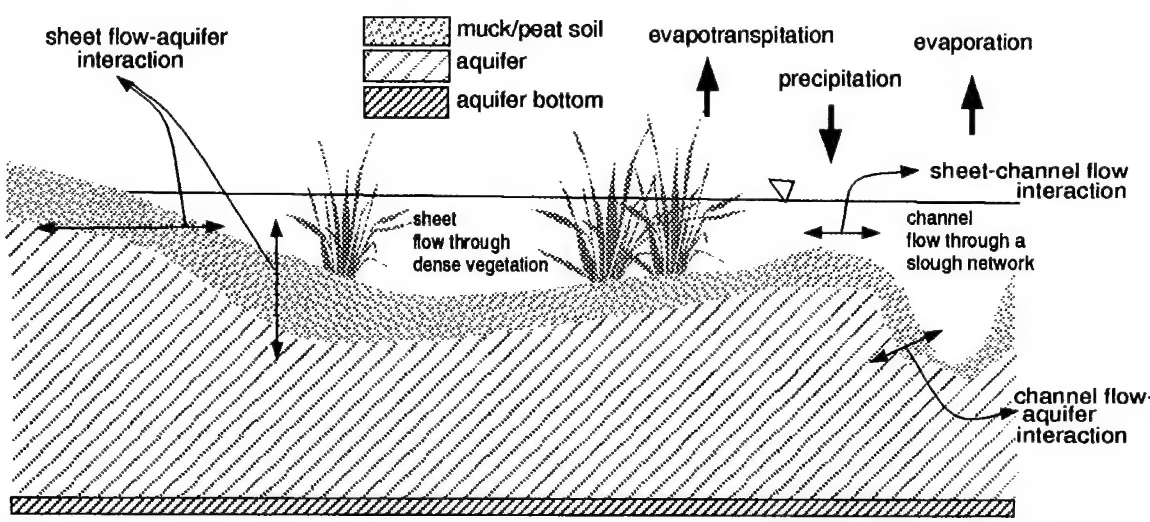


Figure 42. Schematic of Wetland System Representation. Source: After Restrepo *et al.* 1998.

The Wetland Package uses a semi-empirical Manning-type equation (Kadlec 1990) rather than Darcy's Law to represent surface water movement through dense vegetation. The Kadlec equation is given by:

$$q = K_w h^{\beta} S_f^{\alpha} \qquad \textbf{Equation 1}$$

where q is the discharge per unit width (L^2/T); K_w is the hydraulic conductance coefficient for overland flow ($L^2/T/L^{\beta}$); h is the flow depth (L); β is an exponent related to microtopography and the stem density-depth distribution; S_f is the hydraulic gradient; α is an exponent that reflects the degree of laminar or turbulent flow conditions. An explanation of the mathematical formulations for the package may be found in Restrepo *et al.* (1998).

This package is suitable for modeling the wetting and drying of the wetlands by combining vegetation and soils (under the ponded water in **Figure 42**) as part of model layer 1. This approach allows the flow equations to remain valid when the water surface falls below the soil surface (i.e., Darcy flow) as shown by the level 2 line in **Figure 43**. When the model is applied to a water ponding case (level 1), the effect of the value of soil transmissivity is insignificant relative to the corresponding value for the surface water, which is governed by Kadlec. However, the soil layer plays an important role in the vertical direction, as is expected.

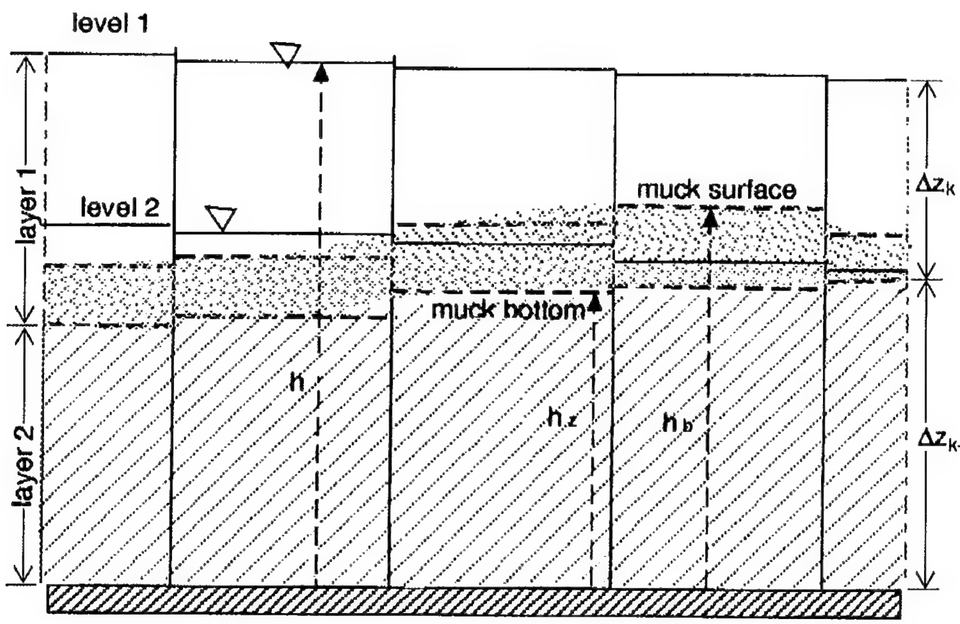


Figure 43. Surface and Groundwater Representation in Wetland Package. Source: After Restrepo *et al.* 1998.

The Wetland Package simulates preferential flow paths and vertical impermeable barriers to both horizontal overland and groundwater flow. These features will either increase or decrease the flow rate. Levees and sloughs are indirectly defined as a hydraulic characteristic by using the cell faces for the interblock transmissivity to designate preferential flow orientations. In the case of fully or partially penetrating barriers, the package has the option of completely restricting flow through the cell face or allowing some seepage through the face. The establishment of barriers to flow requires the user to specify which cell faces in the modeled feature are perpendicular to the cell flow in order to block the flow. Specifying preferential flow paths requires the user to select the cell faces in the modeled feature that will follow the primary spatial extent of

the slough to allow water to move freely down a path. This methodology works best when the principal direction corresponds to the grid orientation.

Diversion Package

The Diversion (DIV) Package was developed by the SFWMD and the Center for Hydrology and Water Resources at Florida Atlantic University (FAU) (Restrepo *et al.* 1998). The current version has been revised and improved by FAU in association with the District, as the package has been applied to subregional models in south Florida. The package was created to simulate the effects of man-made structures such as pumping stations or drains on groundwater and surface water levels. Originally designed as a part of the Wetlands Package (Restrepo *et al.* 1998), it was subsequently developed as an independent package in order to utilize its features in a wider range of situations.

The Diversion Package defines water control structures as those structures that regulate groundwater or surface water levels on a seasonal basis. The operational rules of these structures will vary seasonally and in response to extreme weather events such as droughts or hurricanes. In general, during wet periods, water control structures remove water from a basin to prevent flooding. In dry periods, water is retained in basins in order to maintain groundwater levels for crops or to deter saltwater intrusion in coastal areas.

The Diversion Package routes water according to operational rules or physical constraints of the system by conserving mass balance (keeping the water in the system). The water is supplied by a group of source cells, and is distributed to a group of sink cells associated with each structure. Sources and sinks can be external or internal cells or areas outside of the model domain. External cells are located outside of the active model domain; internal cells are always located inside the active model area. Sources may be located outside the active domain (e.g. external surface storage which makes deliveries within the active area). Sinks may be located inside the active domain (e.g., a swale which receives water from a source). Source and sink sets should be defined based on particle travel times of one to two times the length of the time discretization.

The Diversion Package implemented flows due to pumping by adding the source and destination (layer, row, and column) of the cell to which the drain flow is directed. If no destination cell is specified or if the destination cell is inactive, the package functions exactly like the Drain Package. In the case of pumping, the withdrawal rate is calculated as the product of the pumping flow (given by the user) and efficiency factor. This package can be used, for example, to represent the removal of water from a reservoir and dispersal onto a nearby wetland or swale; or to an injection into an ASR well.

Structures have an optimum level at the head (upstream) and at the tail (downstream). The package redistributes the ground water flows from source to sink cells, according to the operational rules of the structure which are based on control levels. The case of diversion flow by a pumping station is depicted in **Figure 44** below.

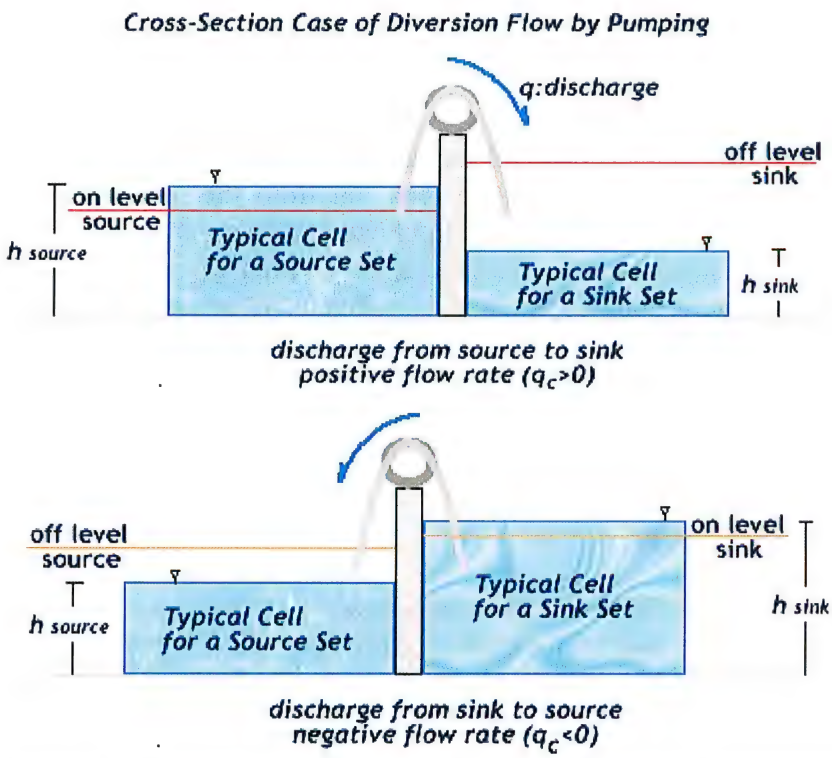


Figure 44. Cross-Section Diagram of Diversion Flow at a Pumping Station. Source: After SFWMD 2005.

The flow rate variable, q_c is supplied by the user for each stress period and represents the movement of water from source to sink (for $q_c > 0$) or from sink to source ($q_c < 0$). The term on level source refers to the lowest water level limit in a source at which water can be released to the sink. Off level sink is the highest water level limit in the sink cells at which they can receive water from the source. In the case of positive flow ($q_c > 0$), the water level in the source cell (hydraulic head at source = h_{source}) will be greater than or equal to the on level source limit and the water level in the sink (hydraulic head at sink = h_{sink}) will be less than or equal to the off level sink limit. Off level source is the highest water level at which source cells at the structure can receive water from the sink. On level sink is the lowest level at which water in sink cells can release water through a structure to source cells. When flow is negative ($q_c < 0$), h_{source} will be less than or equal to the off level source limit, and h_{sink} will be greater than or equal to the on level sink limit. The on/off source/sink levels function as operational rules for the structure, and are specified by the user for both wet and dry seasons.

The package is also used in a wider range of situations such as modeling reservoirs and impoundments, spreader swales and flow ways. Current enhancements allow routing water as series of "cascading" sub-basins and representation of several rules at same location. Flows can be routed from upstream to downstream basins. The basins can include natural and urban areas, but must be specified as active Wetland Package cells. The Wetland Package, in combination with the Diversion Package, will facilitate both channel or sheet flow to move the water to the downstream outlet. In this

case, basin-scale rules of operation or natural drainage characteristics (e.g., change in topography within the source) can be used to control the amount of flow leaving the basin.

Flow ($q_c > 0$) can be predetermined from estimated or historical basin runoff. The model estimates the quantity of runoff that will be removed from the sub-basin and subsequently routed downstream according to the drain elevation. This quantity may be reduced due to the number of cells that actually meet the criteria which are defined by the rules of operation. When a structure does not exist (e.g., tributary to a river), the drain elevation is derived from the topography. The discharge rate released by this structure is constrained by a percentage defined by the number of cells that meet the optimum level in the source and/or sink set. The package redistributes the ground water levels/ surface water levels from source to sink cells that meet this condition.

Reinjection Drainflow Package

The Reinjection Drainflow (RDF) Package was created in 1999 for the SFWMD by McDonald Morrissey Associates, Inc. to simulate a drain from which flow could be directed into another cell rather than being permanently removed from the groundwater flow system, as is the case in the original Drain Package (Jones 1999). The reinjection option is invoked by adding the destination (layer, row, and column) of the cell to which the drain flow is directed. The user specifies both a source destination and a sink destination. The destination in the RDF is similar to the source and sink concept from the Diversion Package (Restrepo *et al.* 1998); however, the source and sink destinations in the RDF have a 1:1 relationship while the Diversion Package source and sink sets have a many to many relationship. If no destination cell is specified or if the destination cell is inactive, the RDF Package functions exactly like the Drain Package. The reinjection rate is calculated as the product of the drain conductance and the elevation of the head in the cell about the elevation of the drain. The RDF Package can be used, for example, to represent the removal of water from a reservoir and dispersal onto a nearby wetland or injection into an ASR well.

Enhancements for the RDF Package were made by FAU (Restrepo 2003) to incorporate a second level for the sink destination cells. The purpose of this second level is to restrict water moving into the sink cells by setting a maximum level. If the heads in the sink cells are below the maximum level, the discharge will be allowed only of the source cells are above the minimum. The benefit of using this approach is that the user can vary the operations on a daily basis, as in an operational schedule, by varying the control levels.

Horizontal Flow Barrier Package

The Horizontal Flow Barrier (HFB) Package was developed by the USGS in order to simulate thin, vertical low-permeability barriers to horizontal groundwater flow. These barriers may be natural geologic features, such as vertical faults; or may be man-made, such as slurry walls, sheet piles, or levees. Prior to the development of this package,

vertical low permeability features were modeled by reduced model grid spacing, or by the introduction of variable grid spacing in the region of concern. The HFB Package allows these features to be represented without increasing the number of model cells, thereby improving efficiency (Hsieh and Freckleton 1993).

Figure 45a shows a plan view of a thin, vertical low-permeability geologic feature in a model layer. This feature is represented in **Figure 45b** as a series of seven horizontal flow barriers located on the boundary between adjacent cells in the finite-difference grid.

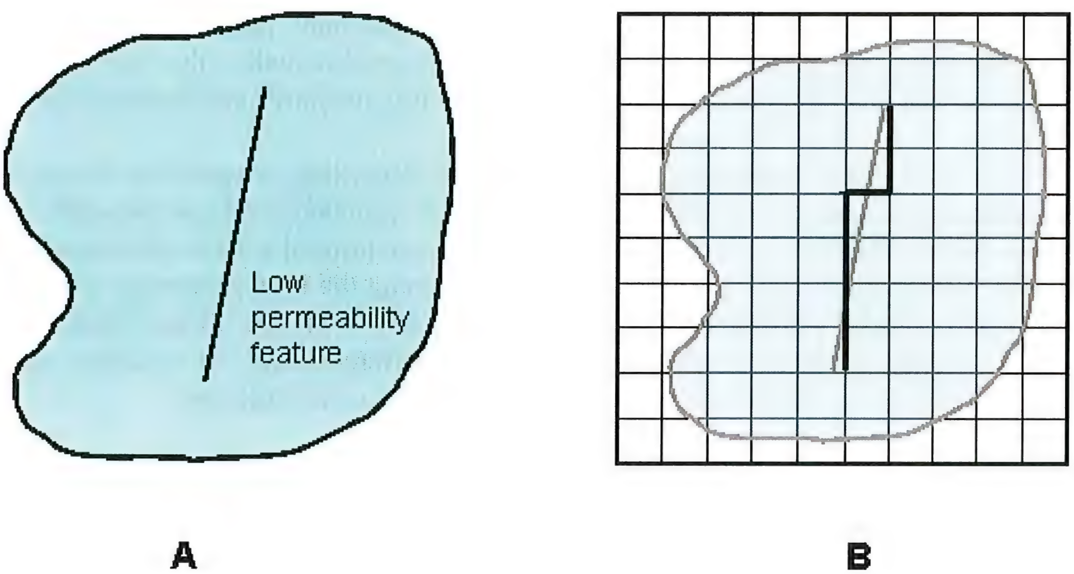


Figure 45. Representation of a low permeability feature (A) and its simulation in the MODFLOW HFB Package as a series of horizontal flow barriers within the model layer. Source: Hsieh and Freckleton 1993.

The HFB Package makes the assumption that the width of the barrier is negligibly small in comparison with the horizontal model cell dimensions. Barrier width is not explicitly defined, but is included implicitly as a hydraulic characteristic either as (1) barrier transmissivity divided by barrier width in a layer with constant transmissivity or (2) barrier hydraulic conductivity divided by barrier width in a layer with variable transmissivity (Hsieh and Freckleton 1993). The HFB Package was not used in model calibration runs for this model; however, it is used in predictive simulations, such as in modeling the L31N Seepage Barrier Pilot Project (Model Application Group 2003).

Trigger Package

The Trigger (TRG) Package was developed in 1992 by the SFWMD and Water Resources Management, Inc. in order to initiate cutbacks in well pumpage in response to head declines in specified "trigger cells". It was originally created for use in the SFWMM and was modified later in 1999 to work with MODFLOW-96 (Randall 1992).

The Trigger Package employs two different methods to reduce pumpage: the cell mechanism and the time_series mechanism. The cell mechanism triggers cutbacks when water levels fall below user-specified limits at selected cells, while the time_series mechanism triggers cutbacks at user-specified time periods, regardless of water levels. Trigger cells are located in areas of concern, and are associated with larger, rectangular zones within the model. A combination of both the cell and the time_series mechanisms determines which zones will be subjected to cutbacks.

In the cell mechanism, a violation is signaled when the head in a trigger cell falls below the specified trigger value. Cutbacks in pumpage are calculated and applied in phases based upon the severity of the violation. The user may require that the violation must occur for a certain number of consecutive stress periods (called the "delay period") before a cutback is applied in order to avoid overreacting to short-term dips in head.

The time_series mechanism applies cutbacks according to specified time periods such as the dry season, or periods when low Lake Okeechobee levels are planned. These cutbacks remain in effect until the end of the dry season, or until a more severe cutback is triggered. Violations occur in phases, with Phase 1 being the least severe by convention. Dry season cutbacks without associated low trigger cell levels are always Phase 1 level cutbacks. If there are trigger cells in a zone having different levels of violation, the cell with the most severe violation determines the cutback phase for that zone.

Pumping reductions are applied to different wells according to their usage type. Some examples of usage types are urban, agricultural, golf, and "zero" type, which means that the well is exempt from cutbacks. When pumpage reductions are triggered, the program outputs two files: one showing where the triggers were set and what phase was assigned, and another showing which wells will have reduced pumpage, and by what amount.

In 2005, source code modifications to the Trigger Package were requested by the Water Use Division at the SFWMD to better reflect existing SFWMD water shortage policies during drought periods. It was necessary to modify the source code by adding a constraint to the logic of the cell mechanism. In south Florida, the wet season lasts from June 1st through October 31st. Historically, the SFWMD's Governing Board has not made a water shortage declaration at the end of the dry season (i.e., April and May), since the wet season would be approaching to bring the needed rainfall. Therefore, an additional user-defined interval or "no cutback window" was programmed to specify times when no cutbacks would occur. It was recommended that the "no cutback window" specification (in the input data) begin on April 1st and end on October 31st.

The Trigger Package was not used for calibration runs because pumpage reductions were represented by actual pumpage records obtained from the SFWMD's Water Use Regulation records. This package is used for predictive scenarios. If the model is re-calibrated, the trigger package must then be re-calibrated as well.

Well Package Modifications and Additions

Rather than modifying the original MODFLOW Well (WEL) Package, a special Trigger Well Package was created by Water Resources Management, Inc. to be used with the Trigger Package. The Trigger Well Package has an added field called "tipe" (the name "type" could not be used, as it is a FORTRAN keyword) which associates a usage type with each well (e.g. urban, agricultural, etc.). It also contains a temporary storage place for input pumpage. This allows the reuse of the previous stress period's pumpage if that pumpage had been reduced by the trigger mechanism.

Both the original Well Package and the Trigger Well Package were modified by the District staff in 1999 to allow wells to be read from multiple files. This is useful when changes are made frequently to certain types of wells (i.e. public supply wells) while other well data remains fairly static. The primary well file will allow up to two additional unit numbers to be included. These changes allow the reuse flag (-1) to be invoked separately for each file. For example, the first file may have 500 wells, the second 20, and the third 10 for the first stress period. In the second stress period, one might decide to reuse all the wells in the first two files, but specify 40 new wells in the third file.

Utility Generation Package

The Utility Generation Package (UGEN) was developed by the Center for Hydrology and Water Resources at Florida Atlantic University, as a tool to generate time-related MODFLOW input during model execution. Traditional MODFLOW input files must be built prior to execution for each package and for the entire simulation period. UGEN creates the input files "on the fly" by linking the static input parameters, such as physical location, with the dynamic temporal data, much like a relational database (Restrepo *et al.* 2003). The static and dynamic data are linked by "location name" identifiers. The UGEN package can be used to generate these MODFLOW packages: River, Drain, Well, General Head Boundary, Reinjection Drainflow, and Diversion. It can also be used to correct heads due to the presence of the salt-water interface and to calculate the hydraulic conductance for the River, General Head Boundary, and Drain packages.

When MODFLOW is run with UGEN, three input files are needed. The first, the UGEN file, defines the number of stations for stages and/or flows and any flags. The second type of input file needed is the observation file. UGEN observation files contain stage and/or flow values for each stress period for all stations. Each record in the observation file represents one stress period, as shown in **Table 6**.

Table 6. Example of UGEN Observation File Displaying Time-Varying Data

ID	Year	Month	Day	Station-1	Station-2	Station-3
1	1990	1	1	14.3	7.9	11.1
2	1990	1	2	14.5	8.1	11.5
3	1990	1	3	14.5	8.0	10.8
4	1990	1	4	14.3	8.3	11.0

The third type of input file is the modified MODFLOW input package file to be used with UGEN (e.g. RIV, DRN, WEL, GHB, DIV, or RDF). This input file will provide the same information that MODFLOW requires. However, instead of having stage or flow values, it will have the location name identifier. This represents the "static" portion of the UGEN input files that the utility links with the "dynamic" information provided in the observation files. These modified MODFLOW input files may be kept constant during all simulations, or may be changed if necessary.

UGEN is completely compatible with MODFLOW in both its modular structure and its programming language (FORTRAN). When activated within MODFLOW, UGEN saves both storage space and execution time. The placement of the static data and time-series data into separate files also reduces model setup time. **Table 7** is an example of a portion of a MODFLOW River Package input file. The first two lines have the same information a normal MODFLOW River Package input file contains. The third line contains the static information that is in the usual input file; however, the stage data is replaced by the station name.

Table 7. Example MODFLOW River Package Input File Formatted for UGEN.

53	0				
1					
1	75	44	500	1.3	Station-1
1	121	39	500	-1.5	Station-2
1	14	208	500	2.4	Station-3
-1					
-1	Indicates data being reused for the last three stress periods				
-1					

Strongly Implicit Procedure Package Enhancements

Two alternative enhancements were developed by the SFWMD in 1998 for the Strongly Implicit Procedure (SIP) Package in order to improve or maintain model stability. Both alternatives have added optional variables. If the variables are not used, the SIP package will function normally.

In Alternative 1, two optional variables are added to the second line of the SIP input file. These are HCLOSEMAX and NOSTOP. When the maximum number of iterations is reached and the maximum head change in a cell is less than HCLOSEMAX, SIP continues to the next time step rather than aborting the simulation. This allows a tight closure criterion (via the original HCLOSE term) for most of the simulation, while tolerating a few problem stress periods. When NOSTOP is included and set equal to 1, the program will not terminate if HCLOSEMAX is violated. Instead, the problem cells

are reset to their values at the end of the last time step and a warning message is written to the output file. This is helpful in trying to improve a model with stability problems.

In Alternative 2, four optional variables were added to the SIP input file. These are MNITER and NITERSL on the first input line, and HCLOSEMAX and DACCL on the second input line. MNITER is the minimum number of iterations. NITERSL is the minimum number of iterations before deceleration is allowed. DACCL specifies the fraction by which the simulation will decelerate. HCLOSEMAX is the same as described in Alternative 1. HCLOSEMAX and HCLOSE together serve as an upper and lower bound. Deceleration allows the model to iterate slower, thereby helping maintain stability. The simulation will terminate if the closure criterion exceeds HCLOSEMAX.

Output Control – Summation Enhancement

The MODFLOW summation utility was developed by the SFWMD as an enhancement to the output control file. Because of the size and long simulation periods used in SFWMD models, and the use of daily stress periods, looking at cell-by-cell flows was an overwhelming task. The summation utility allows the user to sum the cell-by-cell flows after any number of stress periods so that the output data is more manageable.

The enhancement was made by adding the variable INUMSUM to the first line of the output control file, and by modifying the variable ICBCFL. INUMSUM tells the program how many packages there are to be summed, and is specified once per simulation. ICBCFL is the cell-by-cell flow flag. Originally if this variable was 0, flows were not saved, and if it was 1, flows were written to disk. These two options are still available. The enhanced version, however, allows the user the use the number 4 to add the current flows to those in an accumulator, and to use the number 5 in the stress period when the final flows are added to the accumulator and the summed flows are written to disk. Currently the SFWMD practice is to sum the cell-by-cell flows at then end of every month.

Multibud Enhancements

Multibud was originally developed by the SFWMD as a post-processing tool for the subregional models. Due to the Output Control Summation Enhancements, flows are summed to a monthly rate (to save disk space). After model execution, Multibud extracts the flow (or water) budget from pre-defined cells or regions. For example, if Multibud was used to extract the flow budget from one cell, Multibud would provide a time-series of flows from that cell for the length of the simulation. If a region consisted of 50 cells, Multibud would sum the flows from the 50 cells and produce a time-series of the water budget. Multibud produces flow budgets for MODFLOW terms, including: storage, cell-by-cell flows from all six faces, constant head and general head flows, pumping rates, leakage from drains and rivers, ET and recharge rates, flows from water diversions, and reinjected drainflows.

In 2004, the SFWMD's Processing Section proposed to incorporate Multibud to the MODFLOW-96 source code with the intention of producing daily flow budgets without writing MODFLOW's cell-by-cell file for the entire matrix for the length of the simulation. In 2005, with the help of Ecology & Environment, Inc. this idea was implemented and verified for use in the MODFLOW-96 source code.

MODEL DESIGN

The MODFLOW-96 source code has been substantially altered by introducing many add-on packages. For that reason, customized pre- and post-processing tools have been developed to aid in the process of model design, as well as model applications. A combination of mostly FORTRAN, Arc Macro Language (.amls), and geoprocessing programs are used to construct model input and output. In addition, the SFWMD's Processing Section has developed a Performance Measure (PM) Viewer which manages and graphically displays input and output from multiple simulations.

Spatial and Temporal Discretization

The LECsR Model grid is uniformly discretized into 704 foot by 704 foot cells (each cell covering about 11 acres) with 1033 rows and 408 columns resulting in a full grid of 421,464 cells per layer (**Figure 46**). The grid limits, from the lower left corner node coordinates (x_{min}, y_{min}) are given as (680961.0, 318790.0) in U.S. State Plane, Florida East Zone, NAD 83.

In the study area, the hydraulic gradient is from north to south from Lake Okeechobee to the Everglades; water also moves west to east (towards the coast). A larger nodal spacing could be used when the regional water table slopes gradually from about 20 ft, NGVD to 1 ft, NGVD. However, changes in the water table towards the coastline occur over a shorter distance, partly due to induced hydrologic stresses (e.g., pumping wells and canal drainage systems) and could require a smaller nodal spacing. For instance, there can be up to 8-10 feet in elevation change between the headwater and tailwater of a structure (e.g., S-80, S-155 and G-56). Selecting the 704 foot by 704 foot cells was a compromise between the regional (i.e., large nodal spacing) and local (i.e., small nodal spacing) hydraulic gradients. Moreover, the cell size of 704 foot by 704 foot was selected in order to interface with the SFWMM's 2 mile by 2 mile cells for predictive runs. Consequently, there are 225 LECsR Model cells within 1 SFWMM cell.

The model will be run under transient conditions. A steady-state version of the model will not be developed, since the south Florida hydrologic system is very dynamic (e.g., wellfield withdrawal rates vary, operational changes over time). The temporal discretization was chosen to accurately reflect the hydrologic system changes (e.g., rainfall and canal stages) over a recent wet and dry cycle representative of 1-in-10 year events. Daily input data were available to construct the hydrologic packages (i.e., ET, Recharge, River, Drain, General Head Boundary, and Operations) and excluded pumping

stresses. Average monthly pumping rates (fluxes) were used to generate daily withdrawals because the pumping records are compiled monthly.

A temporal discretization of one day was chosen. This discretization will be applied as a one day time step in a one day stress period. A daily stress period was selected for the following reasons:

- Groundwater levels have been observed to vary due to rainfall on a daily basis.
- Groundwater levels have been observed to vary considerably (e.g., 6 inches) due to the individual or combined effects of canal drainage, overland flow, and wellfield withdrawals in time periods of less than a week.
- Considerable portions of the model are impacted by drainage systems in which the canal stages may change in a single day.
- The natural areas (e.g., J.W. Corbett Wildlife Management Area) provide considerable surface water storage which can not be accurately modeled during wet periods (when the groundwater is above the ground surface) with a weekly or monthly average value.
- Evaluation of structural (e.g. pump sizes) and operational rules (stage discharge relationships) are more easily and intuitively incorporated using a daily time step.
- Wetland hydroperiods can be highly variable (e.g., inundation periods of less than one month).

This uniform grid and daily stress period allow for an adequate level of subregional accuracy with manageable run and post-processing times. A SFWMD computer analyst estimated disk space and processing requirements for several model grid designs based upon the SFWMM domain.

Table 8. Initial Estimated Processing Requirements for the LECsR Model.

WMM Row	WMM Col	Cells/WMM Cell	LECsR Model Layers	Total LECsR Cells	Total Bytes 36 year daily Heads.dat	Total Bytes 36 year monthly Flows.dat	Approx Output Size	Cell Size (ft)
65	41	225	3	1,798,875	94,548,870,000	46,626,840,000	109,659,420,000	704
65	41	100	3	799,500	42,021,720,000	20,723,040,000	62,744,760,000	1056
65	41	400	3	3,198,000	168,086,880,000	82,892,160,000	250,979,040,000	528
65	41	121	3	967,395	50,846,281,200	25,074,878,400	75,921,159,600	960
65	41	225	4	2,398,500	94,548,870,000	62,169,120,000	156,717,990,000	704
65	41	100	4	1,066,000	42,021,720,000	27,630,720,000	69,652,440,000	1056
65	41	400	4		168,086,880,000			528

				4,264,000		110,522,880,000	278,609,760,000	
65	41	121	4	1,289,860	50,846,281,200	33,433,171,200	84,279,452,400	960

At the time of model design, the Model Application Section was somewhat limited by working across the network and executing models on Sun workstations running Solaris 5.8, primarily SunBlade 150's. The standard configuration for these workstations includes 512 MB of RAM, a 550 MHz UltraSparc processor, and they have local external disks providing 100-400 GB of storage on each. Four terabytes of network disk space became available (via a Storage Area Network (SAN)) months after the initial grid design.

The MODFLOW-96 source code has been compiled using Sun's Forte FORTRAN compiler (version 6.2) under Solaris 5.8 and Digital Visual Fortran (version 6.6) under Windows XP Professional. The compilation is done with an optimization that provides closest to the maximum performance possible for this architecture (level -O4 or –fast).

At the present time, the Section is in the process of migrating over to two, faster Windows-2003 servers through Terminal Services. With hyper-threading activated, there are 8 processors (four virtual and four physical) per server. The total amount of disk storage between the two servers is four Terabytes. Due to large storage requirements of the model, the Section has been asked by the SFWMD centralized Information Technology Department to make every effort to reduce its disk storage requirements.

Overall, the model grid was designed with parsimony by trying to choose a spatial and temporal discretization that would represent the hydrologic system well and keep the disk storage to a minimum. At the same time, it was critical to model the LEC region using a single model. The Section receives more modeling requests for this area than any other within the SFWMD boundary. Often, the modeling requests involve system-wide changes in the LEC. The best way to fulfill the requests is to have one model, even though the computer disk and processing requirements are significant.

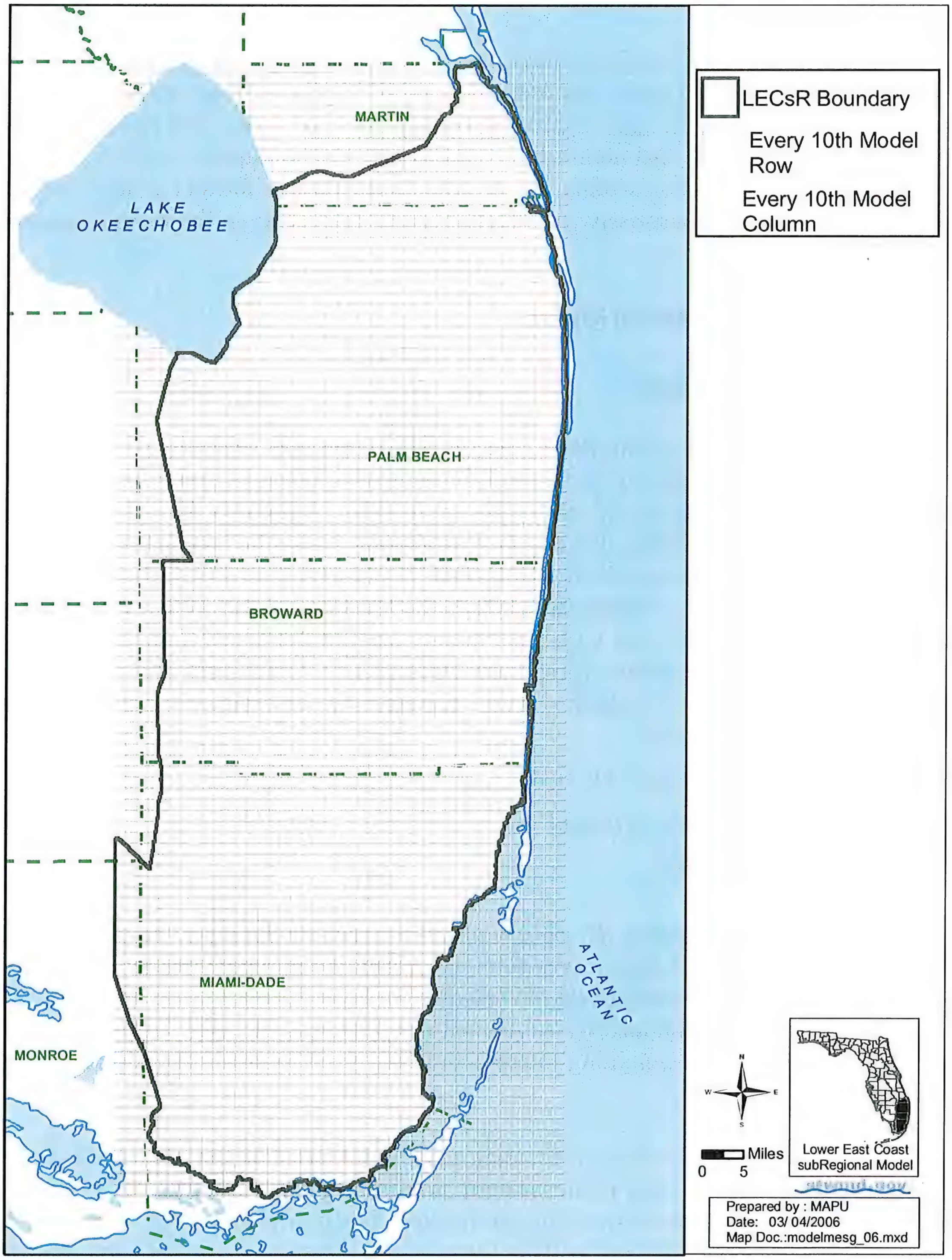


Figure 46. Model Mesh (Displaying Every 10th Row and Every 10th Column).

Groundwater Flow System

The LECsR Model contains three layers comprising the entire Surficial Aquifer System (SAS), providing good representation of the hydrogeologic zones within the aquifer system as well as the partial penetration of canals and wells. The layering scheme incorporates the two principal permeable zones targeted by production wells (i.e., a very high transmissive zone representing the prolific Biscayne aquifer and a more laterally extensive moderately transmissive production zone representing the Gray Limestone aquifer).

Methodology for Model layers

Initial Layer Design

Based on the conceptual model, the LECsR Model was vertically discretized into three layers. With three, active layers the LECsR Model allocates space for roughly 1.2 million cells; about 30 percent of these cells are inactive. **Appendix A** contains geologic wells with x and y coordinates, land surface elevations, hydraulic conductivities for each unit, lithology and thicknesses for the Holocene, Quaternary era (Q5, Q,4, Q3, Q2, Q1), and Tertiary era (T2, T1). **Figure 26** displays the locations of the wells. The wells are distributed over the model area with gaps mainly seen in the Water Conservation areas (WCA's) and in the Everglades Agricultural Area (EAA). Units were grouped based on similar hydrostratigraphic properties (e.g. depositional environments) Model layers consist of the following units:

- Layer 1 - Holocene+Q5+Q4,
- Layer 2 - Q3+Q2+Q1, and
- Layer 3 - T2+T1.

The thickness at each well was calculated for each model layer. To obtain the top of layer 2 the thickness of layer 1 was subtracted from the ground elevation. The top of layer 3 was calculated by subtracting the thickness of layer 2 from the top of layer 2. The bottom of layer 3 was obtained by subtracted the thickness of layer 3 from the top of layer 3. Inverse distance weighting interpolation was used to create the top and bottom surfaces.

Fence diagrams showing the layering scheme are based on the cross-sections from **Figure 18**. The layers thin out in the western portions of the model (**Figures 47 and 49**). Thinning out was not a problem in the north-south direction (**Figure 48**). **Figures 47 to 49** show the thickness based on the IDW interpolation. In some areas the layer thickness needed to be increased for model stability. Near L-47 and L-65 the interpolated top of layer 2 was higher the ground surface (top of layer 1) which is outside the active model area, in these areas the elevation of top of layer 2 need to be lowered. The changes to the model layers are discussed below.

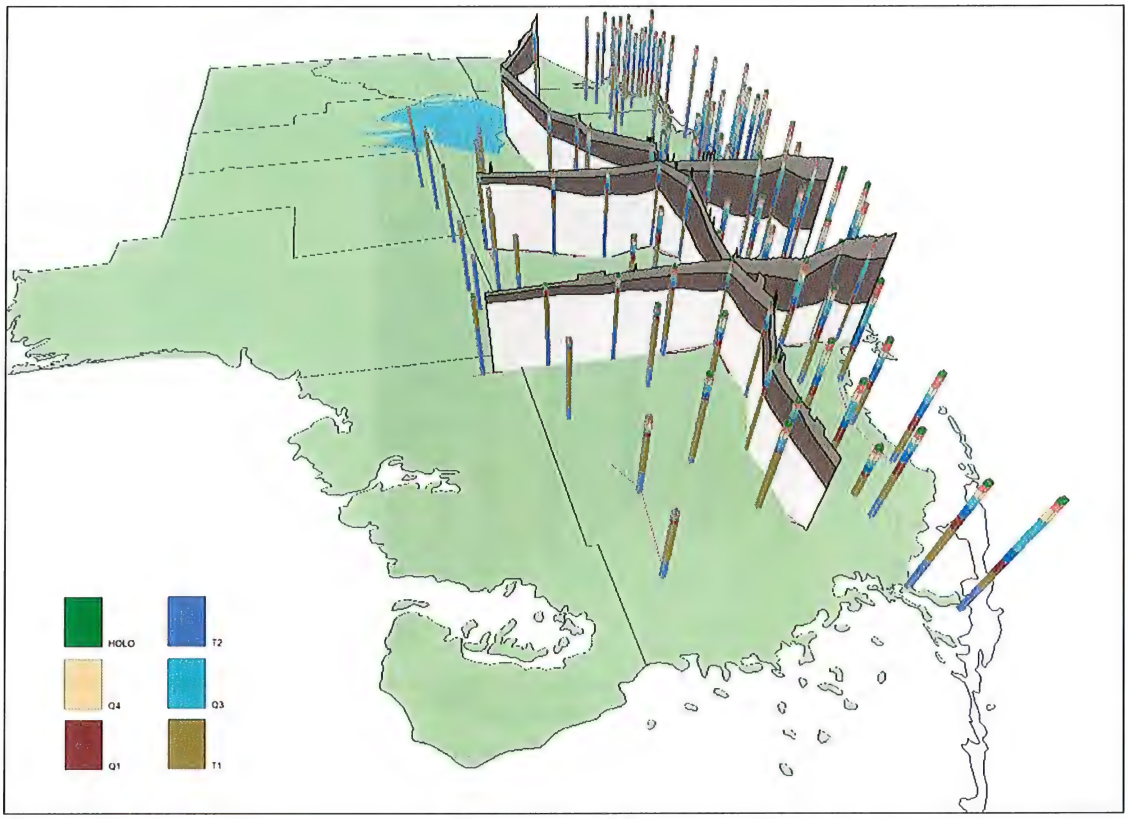


Figure 47. Fence Diagram of Cross-Sections and Model Layering in Study Area.

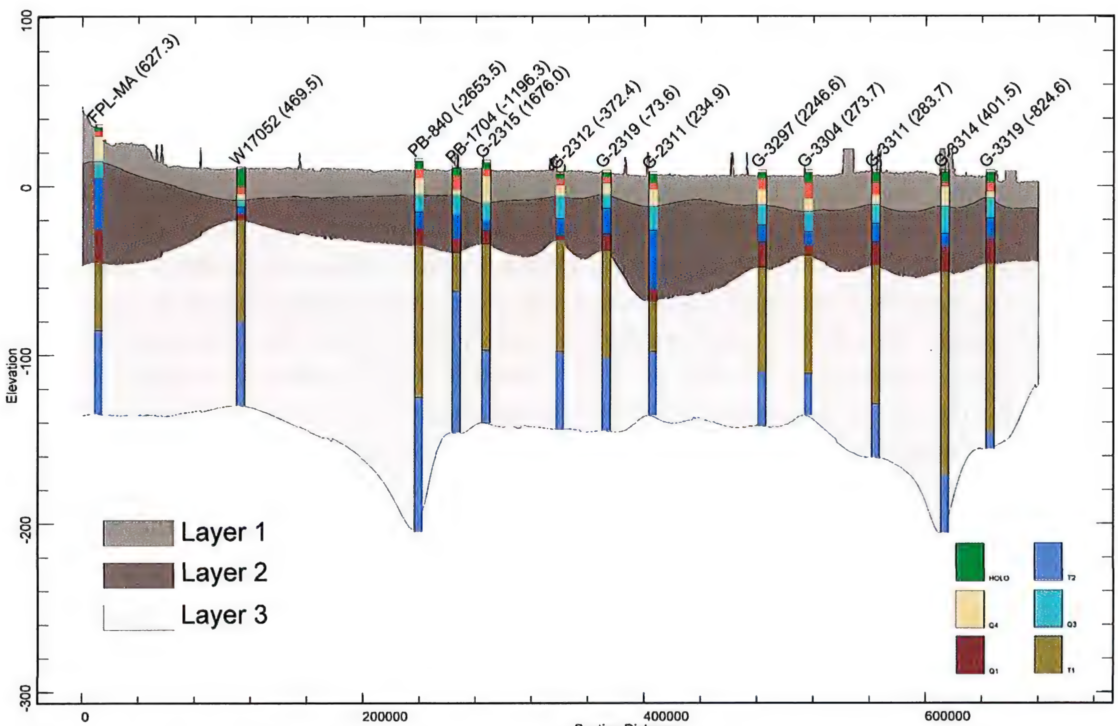


Figure 48. North-South Cross-section B-B' with Model Layers 1 to 3.

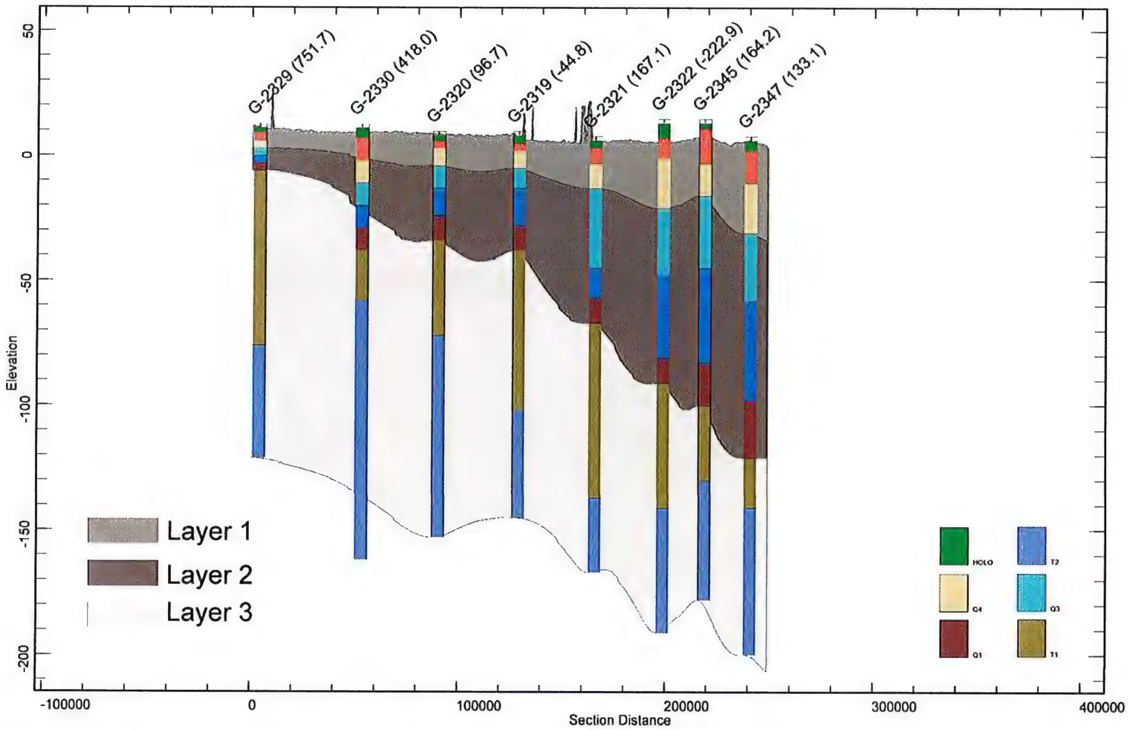


Figure 49. East-West Cross-section D-D' with Model Layers 1 to 3.

Maximum Layer Elevations

In some locations interpolation by IDW generated values for the top of layer 2 that were higher then the ground surface (these areas were outside the active model area). In other areas layers 1 and 2 thin out, as discussed above. For model stability, maximum elevations were applied to the model layers.

Although the layer thickness was not adjusted to reach a better calibration, modifications to the layering scheme were necessary to prevent drying of cells. In the southern and central portions of the model, layers 1 and 2 become extremely thin. As a result, during periods of drought, cells along the western boundary tended to go dry. In order to overcome this problem and produce a more stable model, the maximum value for the top of layer 2 was set to 0.0 feet NGVD. The 0.0 NGVD value was chosen because cells in the extreme southwestern portions of the model are subject to tidal boundary conditions. In addition, the top of layer 3 was set to -10.0 feet NGVD because numerous cells had the bottom of layer 2 above 0.0 feet NGVD in the conceptual model. The bottom of layer 3 was not corrected; it was determined from the contact of the Hawthorn Group

The topographic surface generated from the 100-foot DEM was developed after the model layering scheme. The thickness of layer 1 was originally determined from the geologic control wells. The values at each of the geologic well points should be similar in both the topographic surface and top of layer 1 surface. **Figures 50 to 52** show the model

layers as applied and **Figures 53 to 55** illustrate the thickness of each layer. The model layers were examined to assure that none of the layers crossed (or overlapped).

Layer Properties

Layers 1 to 3 represent the whole SAS; there are no unrepresented confining units. Layer 1 is set to "unconfined" in the BCF package, and contains all river, drain, wetland, diversion, reinjected drainflow, recharge, and evapotranspiration cells. Layer 1 extends from land surface to an elevation of -60 feet NGVD incorporating the unsaturated/saturated zone contact. The bottom of layer 1 was set sufficiently deep to prevent drying of cells especially in areas with variable hydroperiods.

Layer 2 is set to "confined/unconfined" in the BCF package and represents the lower permeable sediments within the upper SAS and the higher permeable limestone of the Biscayne aquifer. This layer extends from about -10 feet to -142 feet NGVD. The bottom of this layer resides in the Biscayne aquifer.

Layer 3 is set to "confined/unconfined" in the BCF package and represents the Gray Limestone/Lower Tamiami aquifer within the lower SAS. This layer extends from about -67 feet to -246 feet NGVD. The bottom of this layer resides at the top of the Peace River Formation.

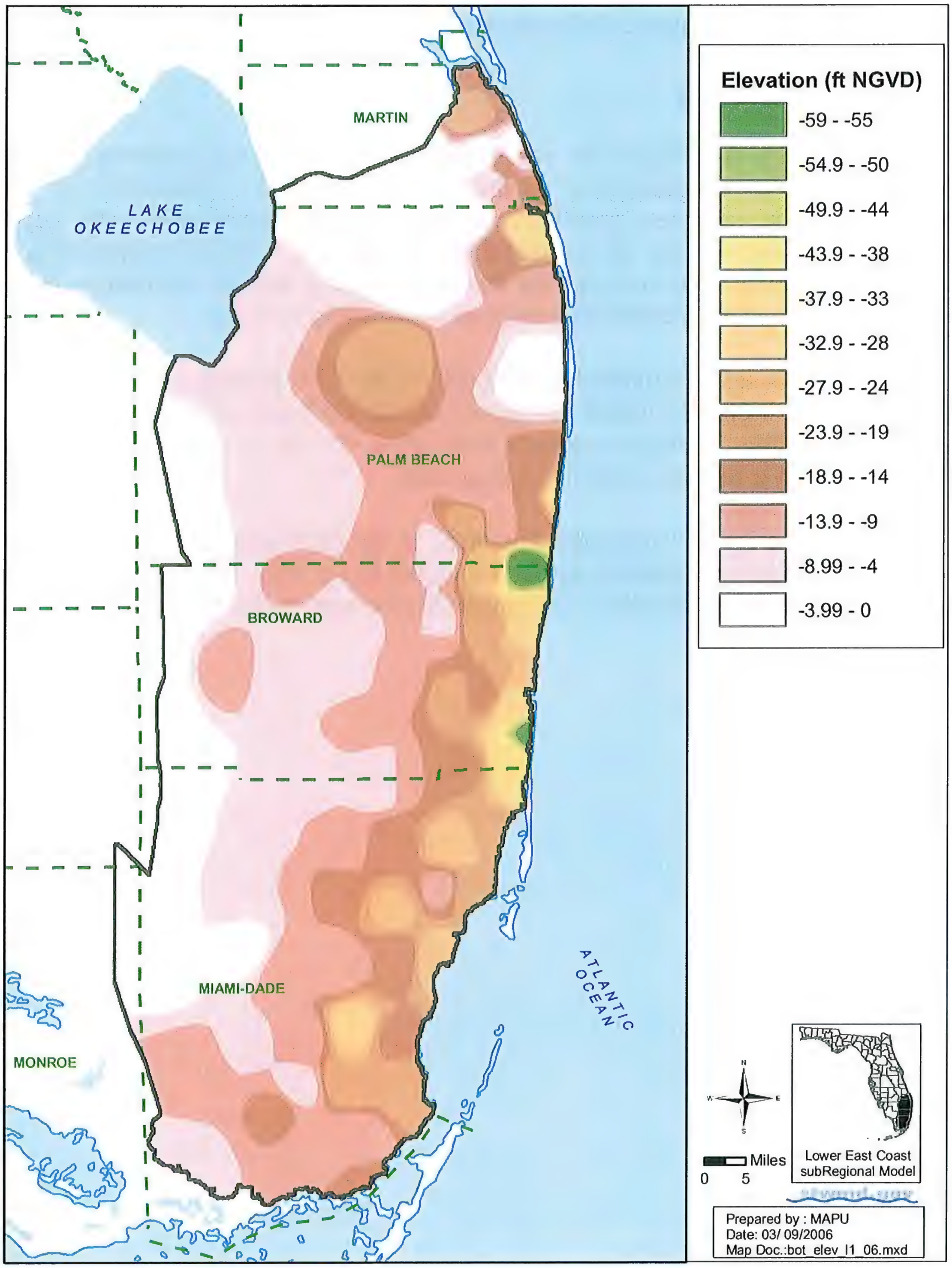


Figure 50. Top of Layer 2 in feet NGVD1929.

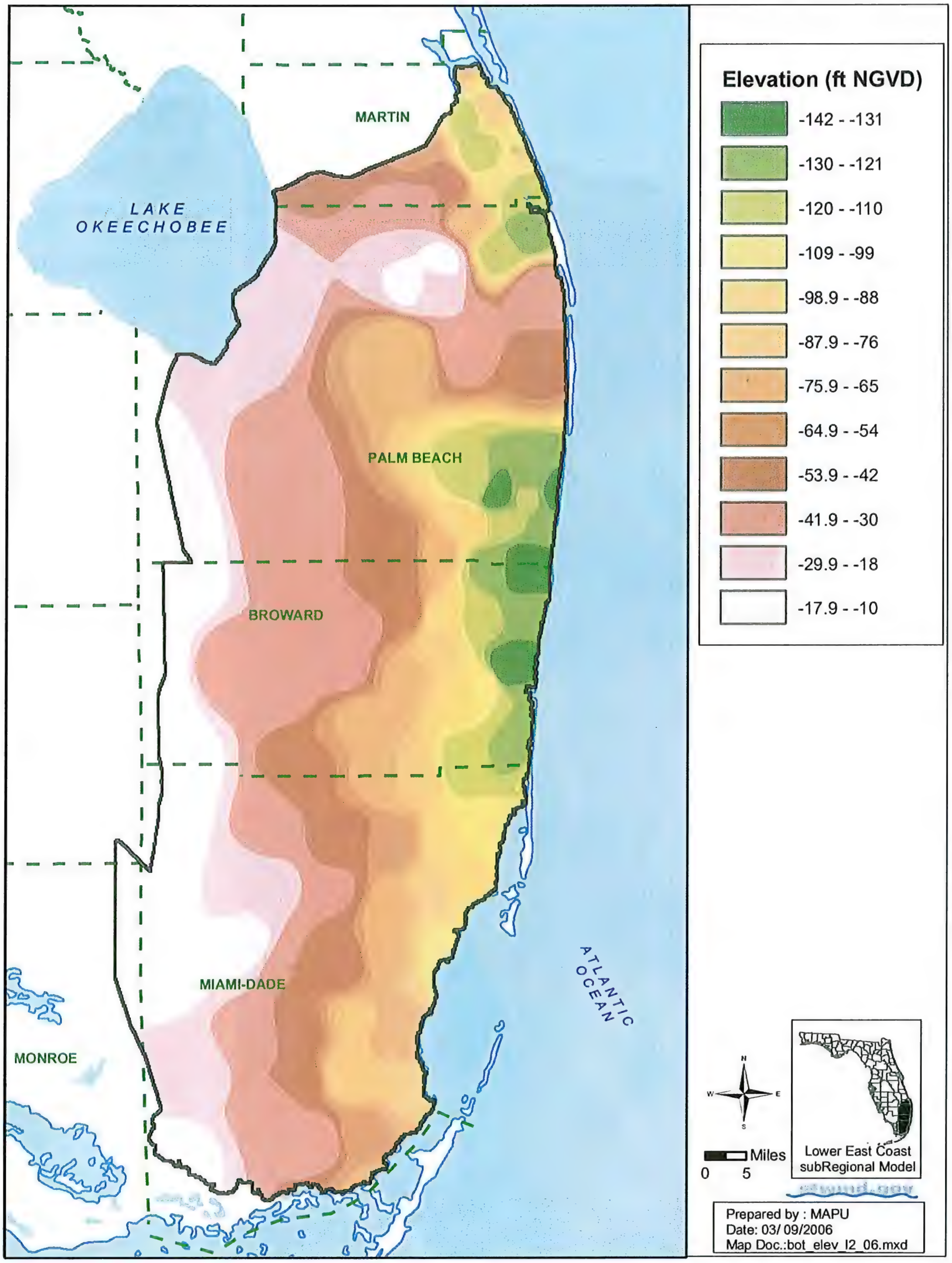


Figure 51. Top of Layer 3 in feet NGVD1929

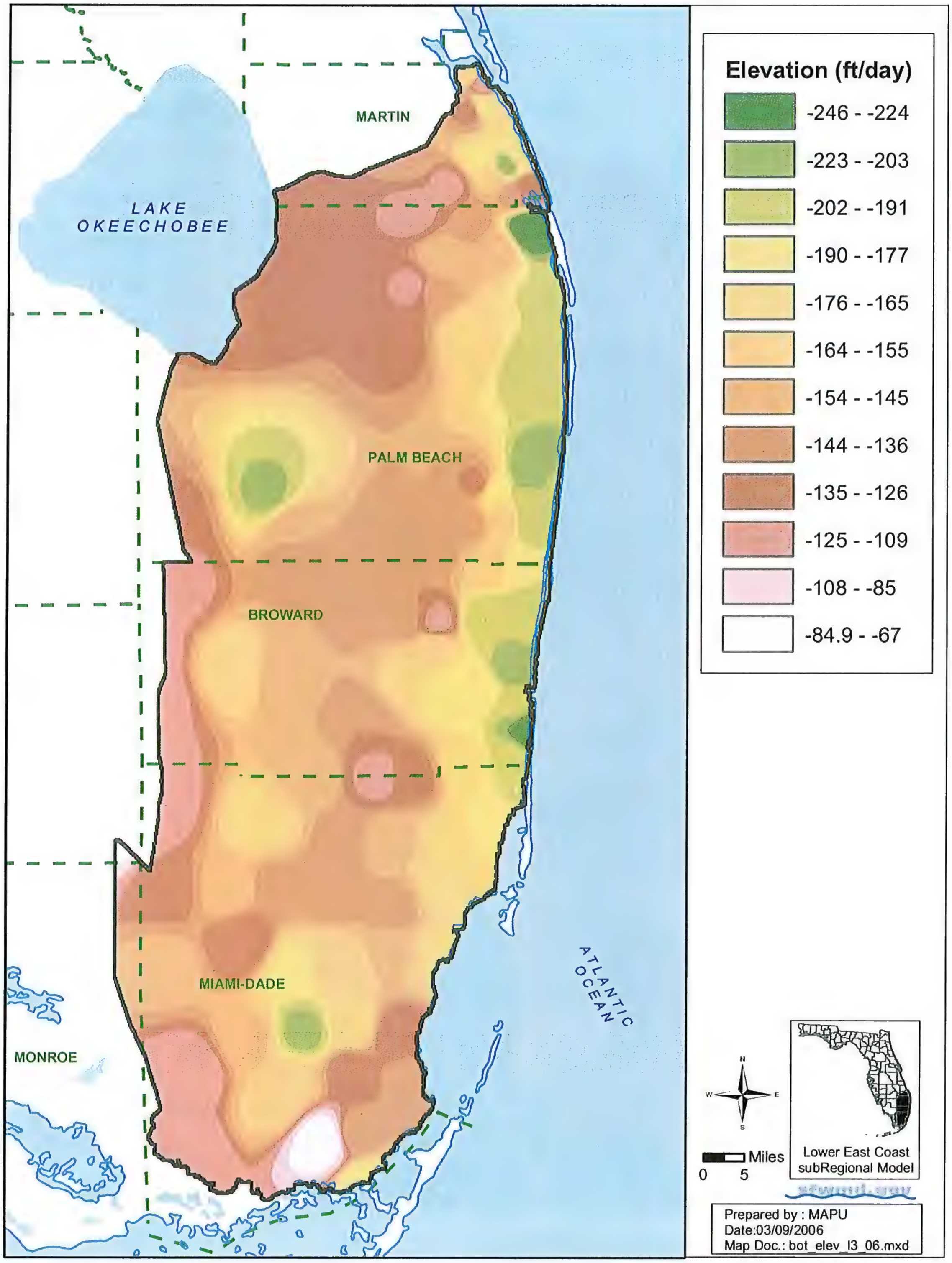


Figure 52. Bottom of Layer 3 in feet NGVD 1929

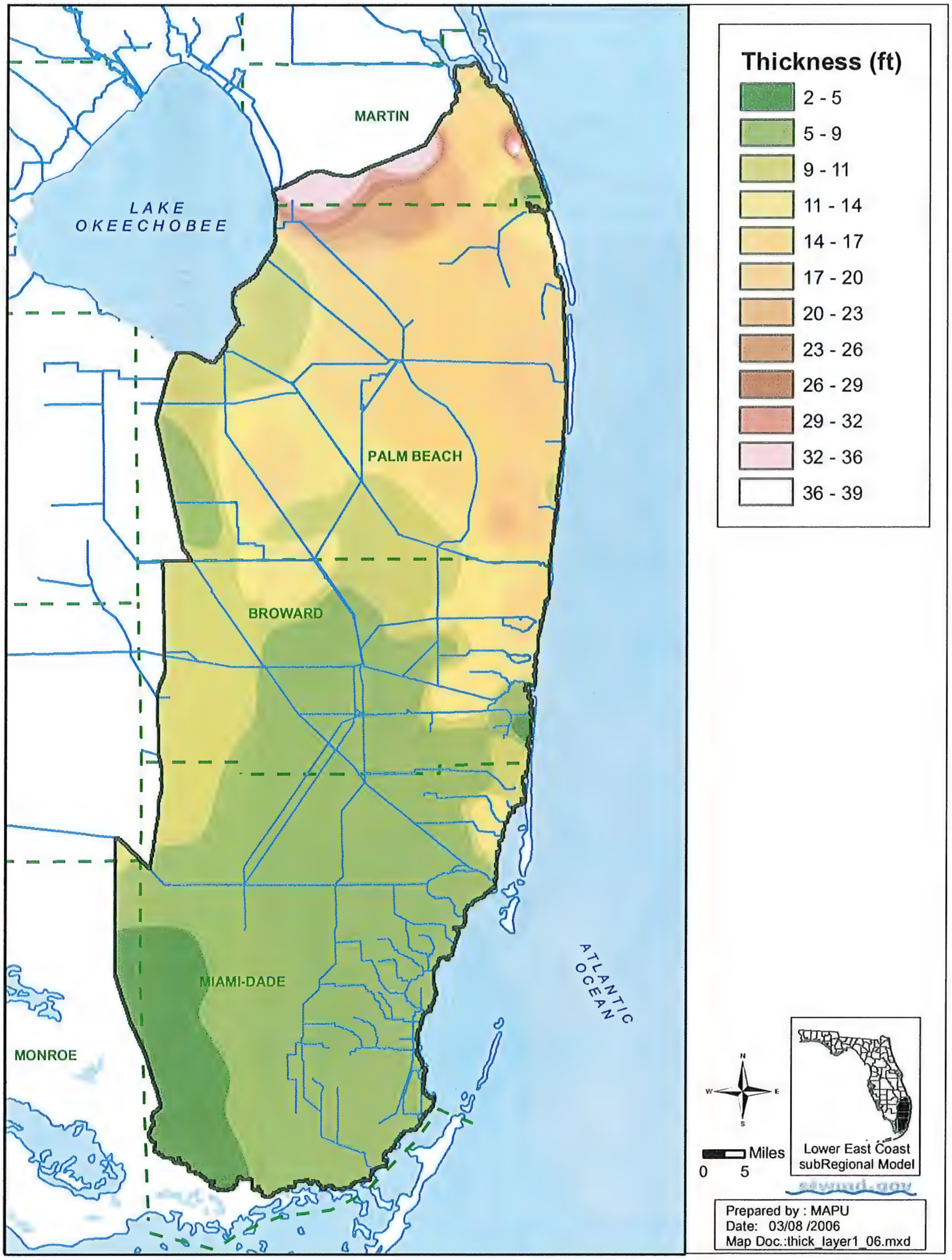


Figure 53. Thickness Layer 1 in feet NGVD 1929

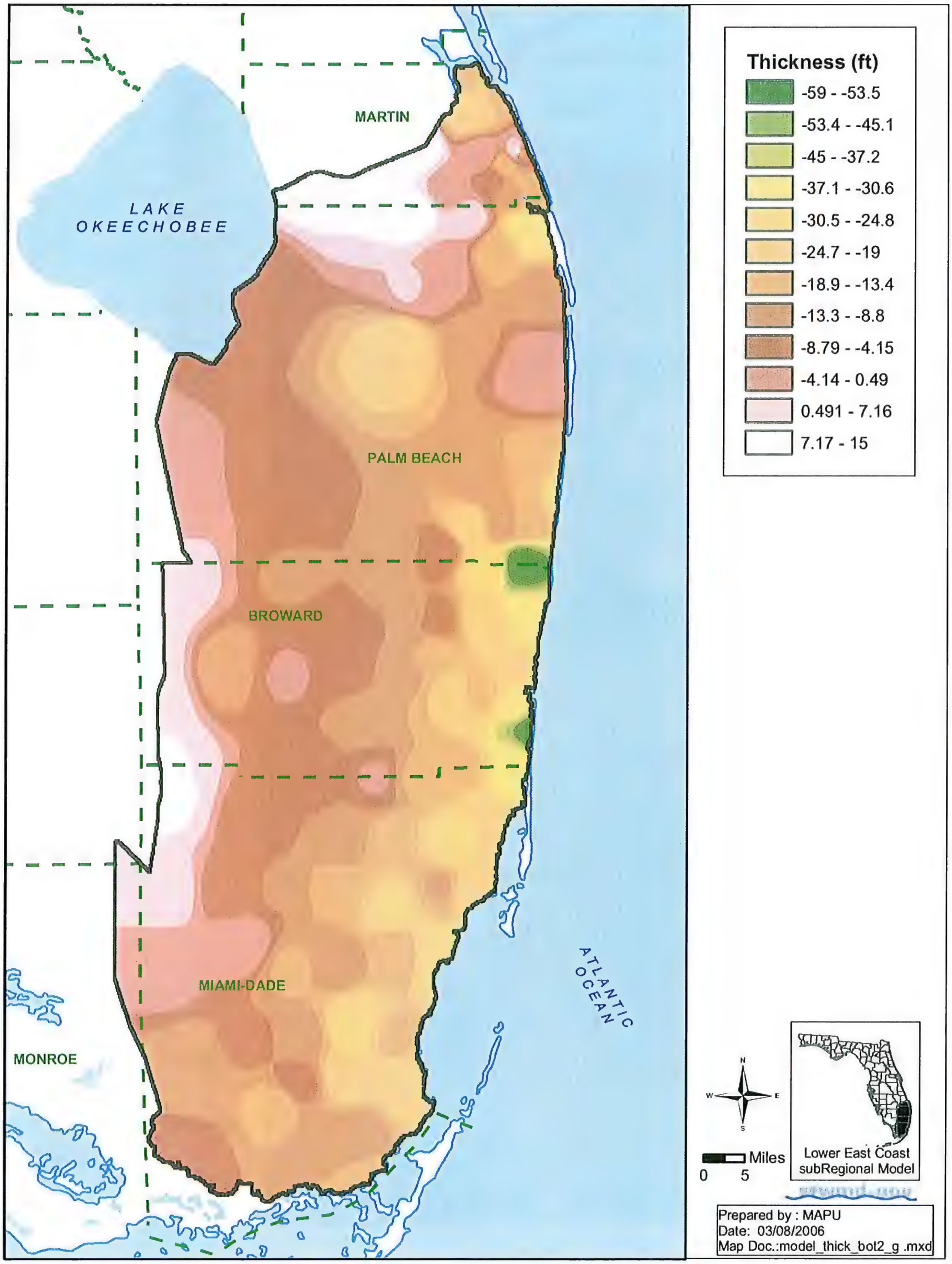


Figure 54. Thickness of layer 2 in feet. NGVD 1929

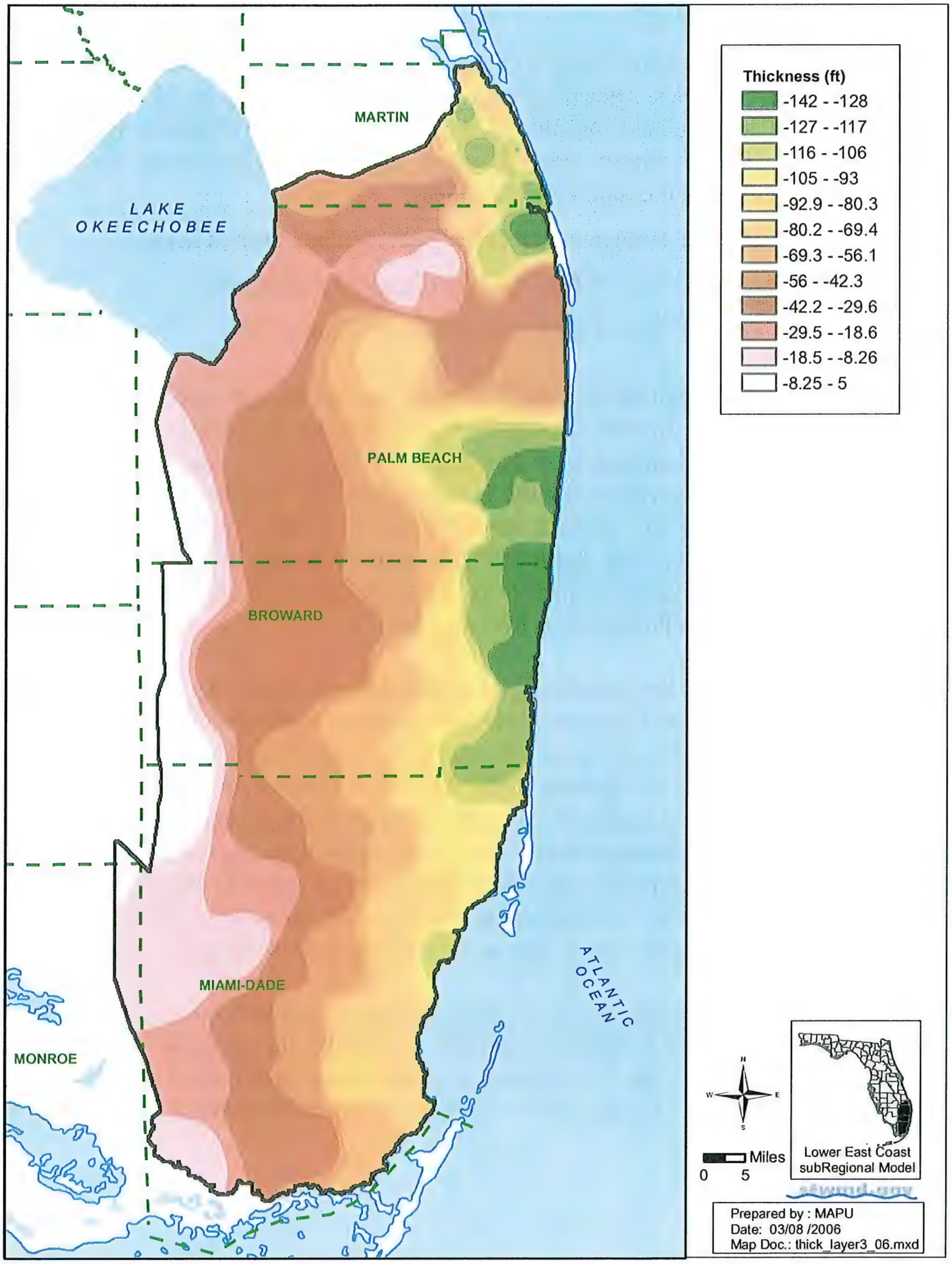


Figure 55. Thickness of Layer 3 in feet NGVD 1929

Hydraulic Conductivity

The hydraulic conductivities (H_k) for each well in each layer were calculated by first computing the transmissivities (T) for each unit (Holocene, Q5 to Q1 and T2 to T1). The transmissivity is calculated by multiplying the hydraulic conductivity for each unit by the thickness. The hydraulic conductivities are determined by the sum of the transmissivities divided by the total layer thickness.

- Layer 1 H_k = (T Holocene + T Q5 + T Q4) / (Thickness of layer 1)
- Layer 2 H_k = (T Q3 + T Q2+ T Q1) / (Thickness of layer 2)
- Layer 3 H_k = (T T2 + T T1) / (Thickness of layer 3)

The hydraulic conductivity surfaces were created in the same manner as the geologic surfaces, using Inverse Distance Weighting on the points. The hydraulic conductivity for model 1 (composite of Holocene, Q5 and Q4) is shown in **Figure 56**. The hydraulic conductivity values for the Holocene are low (below 50 fee/day) for the whole LECsR area. In Q5 and Q4 test values of above 10,000 feet /day were measured for Miami – Dade County. The hydraulic conductivity for layer 1 ranges from 20 to 18,500 ft/day. Low hydraulic conductivities are observed in the northern counties and much higher hydraulic conductivities in Miami-Dade.

The methodology for computing the hydraulic conductivity in layer 2 varied slightly from the other layers as data from two additional sources were available. The hydraulic conductivities for the units Q3-Q1 were derived solely from the geologic control wells as displayed in **Figures 32 to 34**. The locations for the geologic control wells, specific capacity tests and APT's used in layer 2 are shown in **Figure 26**. The additional data for hydraulic conductivity was based on specific capacity tests and aquifer performance tests (APT) from the main production zone. **Figure 57** shows the hydraulic conductivity values for layer 2, which ranges from 1 to 75,000 ft/day. The data from the APT and Specific Capacity increased the number of data points along the coast

The hydraulic conductivity for model 3 (composite of Holocene, Q5 and Q4) are shown in **Figure 56.** The hydraulic conductivity values for periods T2 and T1 are displayed in **Figures 35 to 36**. The hydraulic conductivity values for Layer 3 are much lower then layers 1 and 2. Layer 3 is the thickest of the three layers at most of the well locations seen in **Figure 55**.

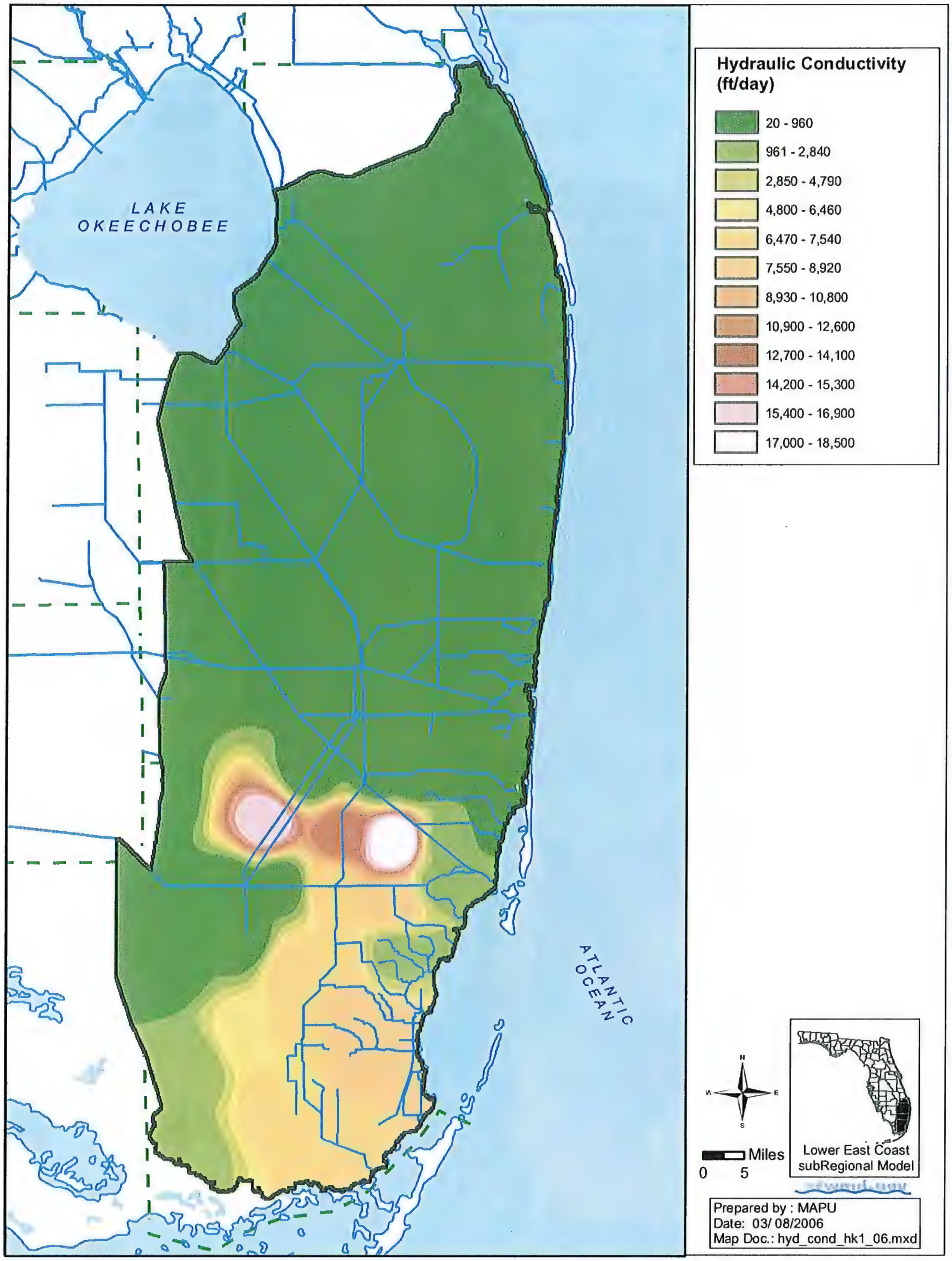


Figure 56. Hydraulic Conductivity of Layer 1 in feet/day

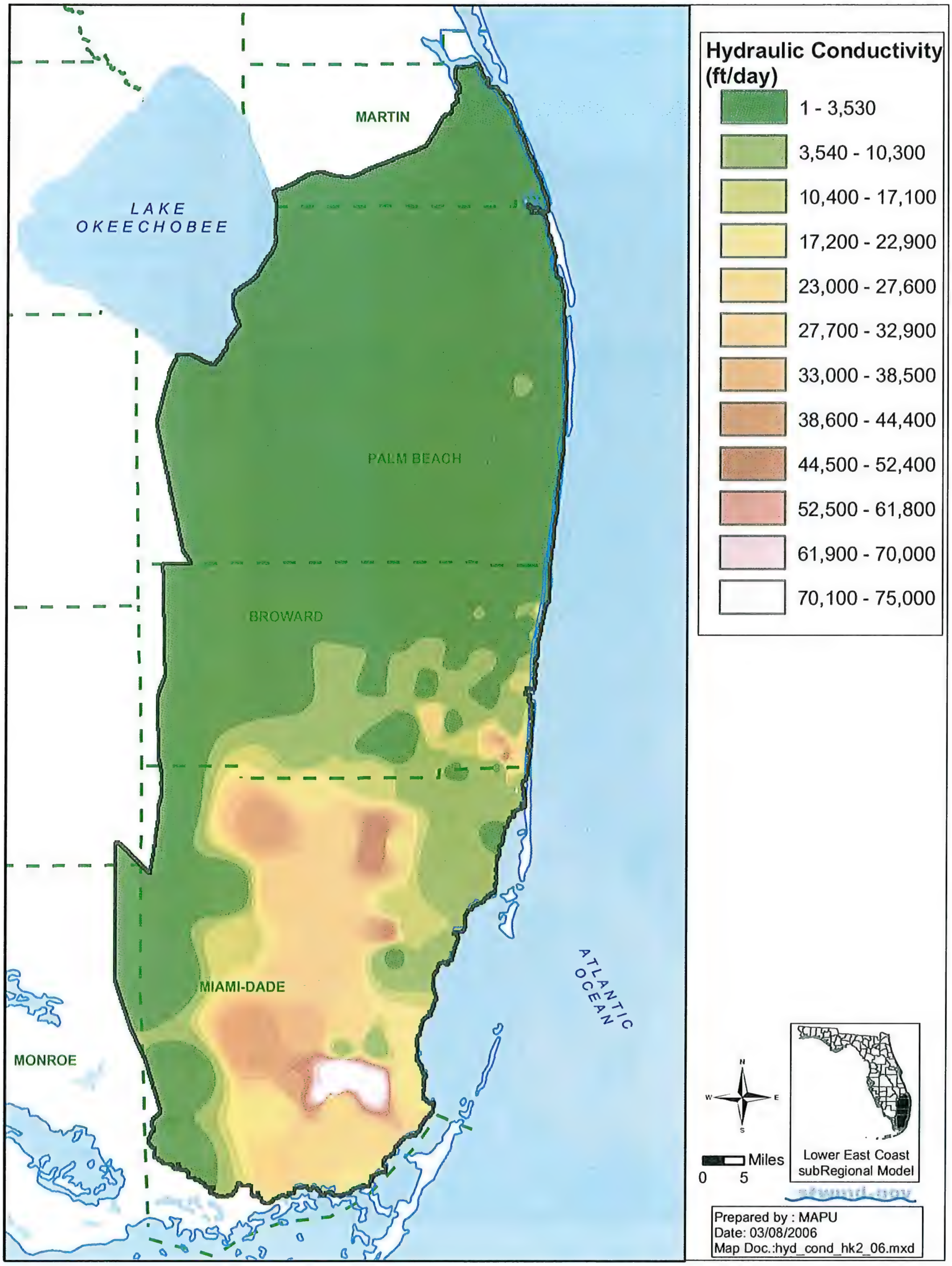


Figure 57. Hydraulic Conductivity of Layer 2 in feet/day

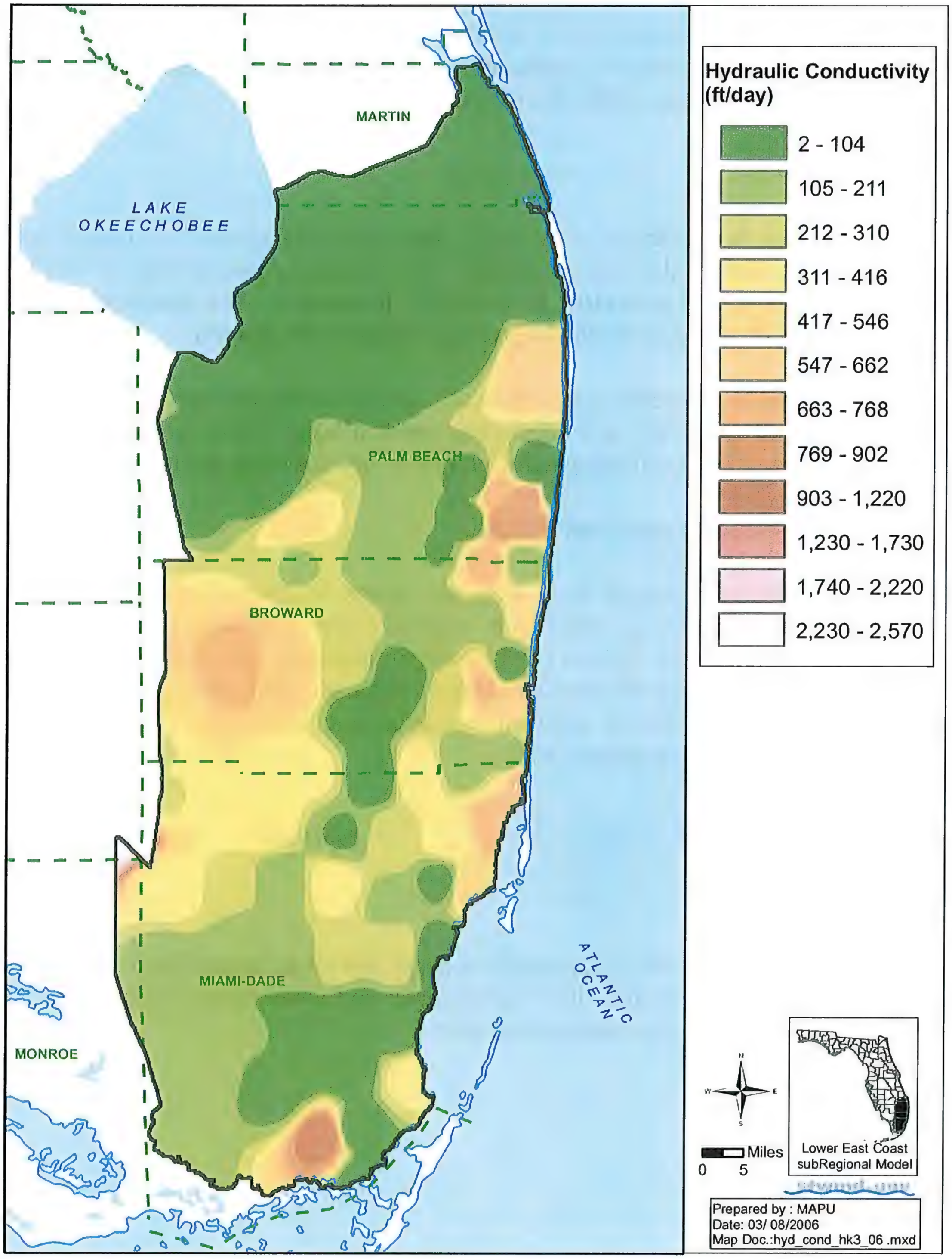


Figure 58. Hydraulic Conductivity of Layer 3 in feet/day

Storativity

The specific storage is the volume of water released from storage per unit change in head per unit change of aquifer for a saturated formation (Fetter 1988). The specific storage is generally very small. A specific storage of $1x10^{-5}$ was used as determined from APT's. Storativity or storage coefficient is estimated as:

$$S = 5.0\,10^{-5}b$$

Where b is the thickness of the layer. The storativity values for layers 2 and 3 were calculated based on the layer thickness. The storativity ranges from $0.85x10^{-6}$ to $0.65x10^{-5}$ in layer 2 and $0.14x10^{-5}$ to $0.85x10^{-5}$ in layer 3. The distribution of the coefficient can be observed in the thickness maps (**Figures 55 and 56**).

Specific yield generally ranges from 0.1 to 0.4 (Anderson and Woessner 1992) and can be derived from APT's. The specific yield in layer 1 was set to the constant, 0.20. Due to the small range of this parameter, it was varied during sensitivity analysis.

Vertical Conductance Coefficient

In MODFLOW vertical flow between layers is controlled by the vertical conductance coefficient (V_{cont}), which is a composite term expressed in units of 1/day. V_{cont} is an expression of the vertical conductivity in confining unit and the thickness of confining unit in that model cell (McDonald and Harbaugh 1988). It is calculated for the two nodes located at vertically adjacent hydrogeologic units (i.e., layers) using the equation (McDonald and Harbaugh 1988):

$$V_{cont} = \frac{1}{\frac{\Delta z_u/2}{K_{zu}} + \frac{\Delta z_l/2}{K_{zl}}}$$ **Equation 2**

where z_u and z_l are the thickness of the upper and lower layers (ft), K_{zu} and K_{zl} are the horizontal hydraulic conductivities for the upper and lower layers (ft/day) and K_{zc} is the hydraulic conductivity for the confining unit.

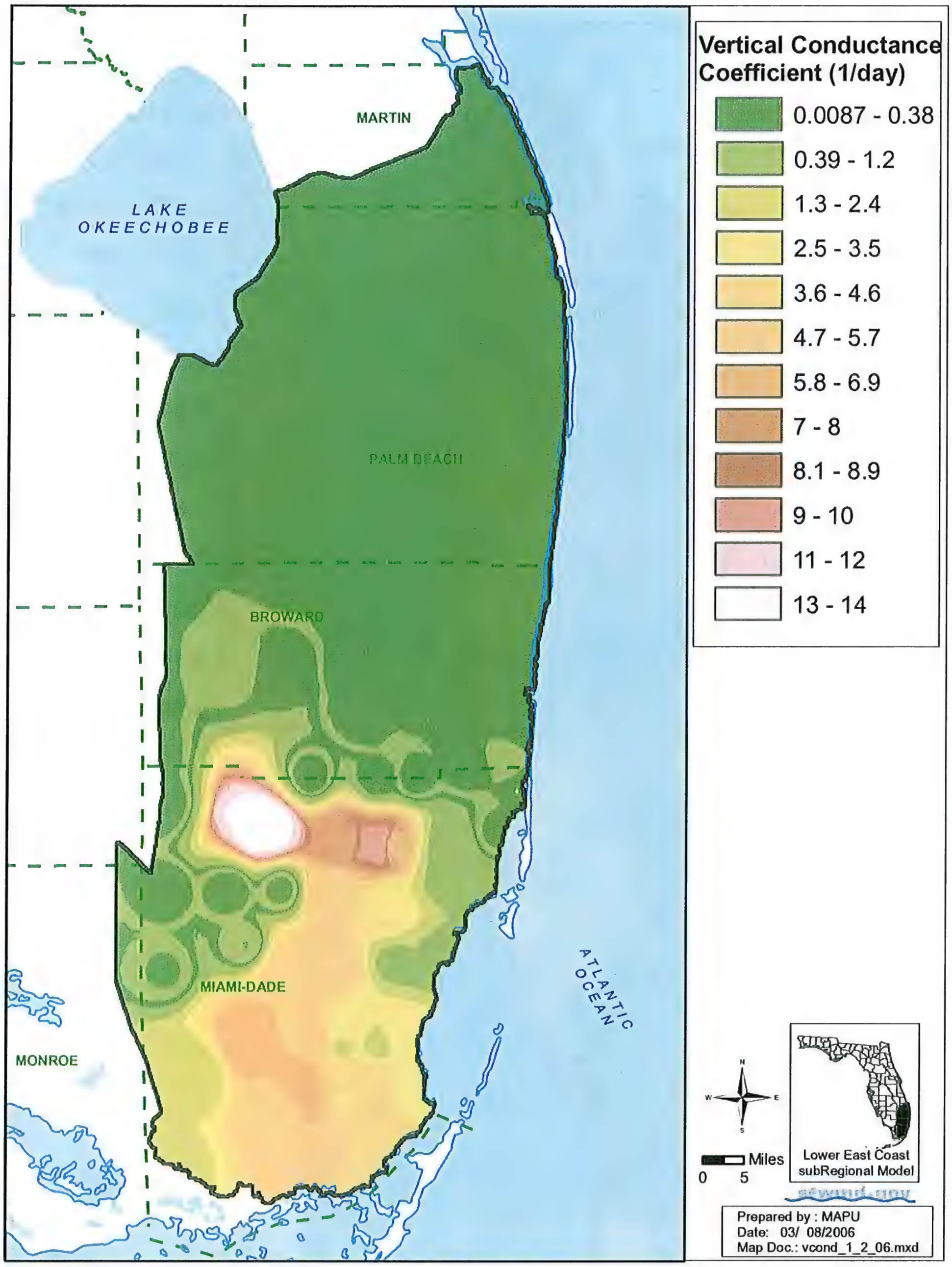


Figure 59. Vertical conductivity coefficient V_{CONT} 12 (1/day) between layers 1 and 2

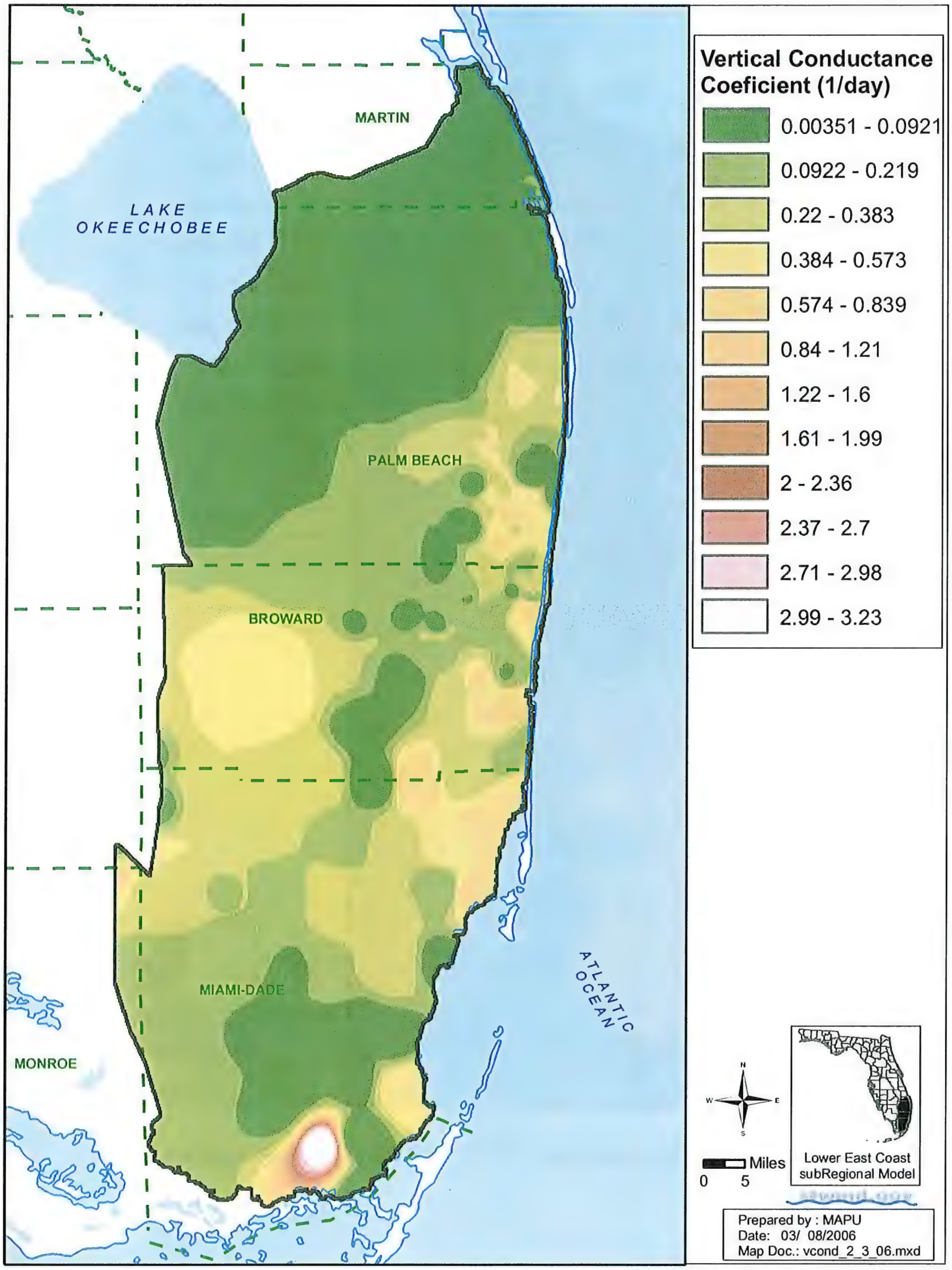


Figure 60. Vertical conductivity coefficient V_{CONT} 23 (1/day) between layers 2 and 3.

In previous studies, vertical anisotropical factor ranged from 0.5 to 0.1 (Restrepo *et al.* 2001, Nair *et al.* 2001 and Wilsnack *et al.* 2000). The vertical anisotropical factor was set to a value of 0.05 due to the extremely high horizontal hydraulic conductivities in the Biscayne aquifer. This represents a 1:20 relationship between the vertical and horizontal conductivity for each cell.

Surface Water Flow System

The surface water flow system in the LECsR Model is simulated using a combination of standard and add-on MODFLOW packages. This approach introduces complexity into the model and distinguishes it from being a purely groundwater flow model. The primary packages that allow the user to represent general operational mechanisms in the south Florida surface water system are Diversion and Reinjection Drainflow. These packages complement the Wetland Package by introducing non-linear flow (i.e., Kadlec) in the upper model layer.

Topography

Input to the Wetland and ET Packages are derived from topography. Input to the ET Package includes the ET surface elevation - the water table elevation at which maximum ET occurs. The Wetland Package identifies the boundary between the surface and groundwater systems which corresponds to the top elevation of muck/peat sediments. Though topography is not explicitly entered as input, it does function as a surface at which fluxes occur; therefore, developing accurate, high resolution topography is beneficial to modeling fluxes.

Data sources shown in **Table 1** were incorporated into the model topography by assigning each model cell with an average value derived from a 100-foot Digital Elevation Model (DEM) constructed for the LEC. The number of points used to calculate model cell averages varied depending on data resolution. The quality of data varied also; however, this data set is considered to be the best available data in the LEC (Hinton 2004). The result was a grid with topography for the 704 ft by 704 ft cells. The next step included overlaying line features of levees. Levee top elevations were identified from the C&SF Project as-built cross-sections for primary canals. Additional levees were identified and added after reviewing satellite imagery and consulting with SFWMD staff. Since model cells are 704 ft wide, most often the levee and canal are within the same cell. **Figure 62** illustrates the land surface elevations and associated levee system within the LECsR Model.

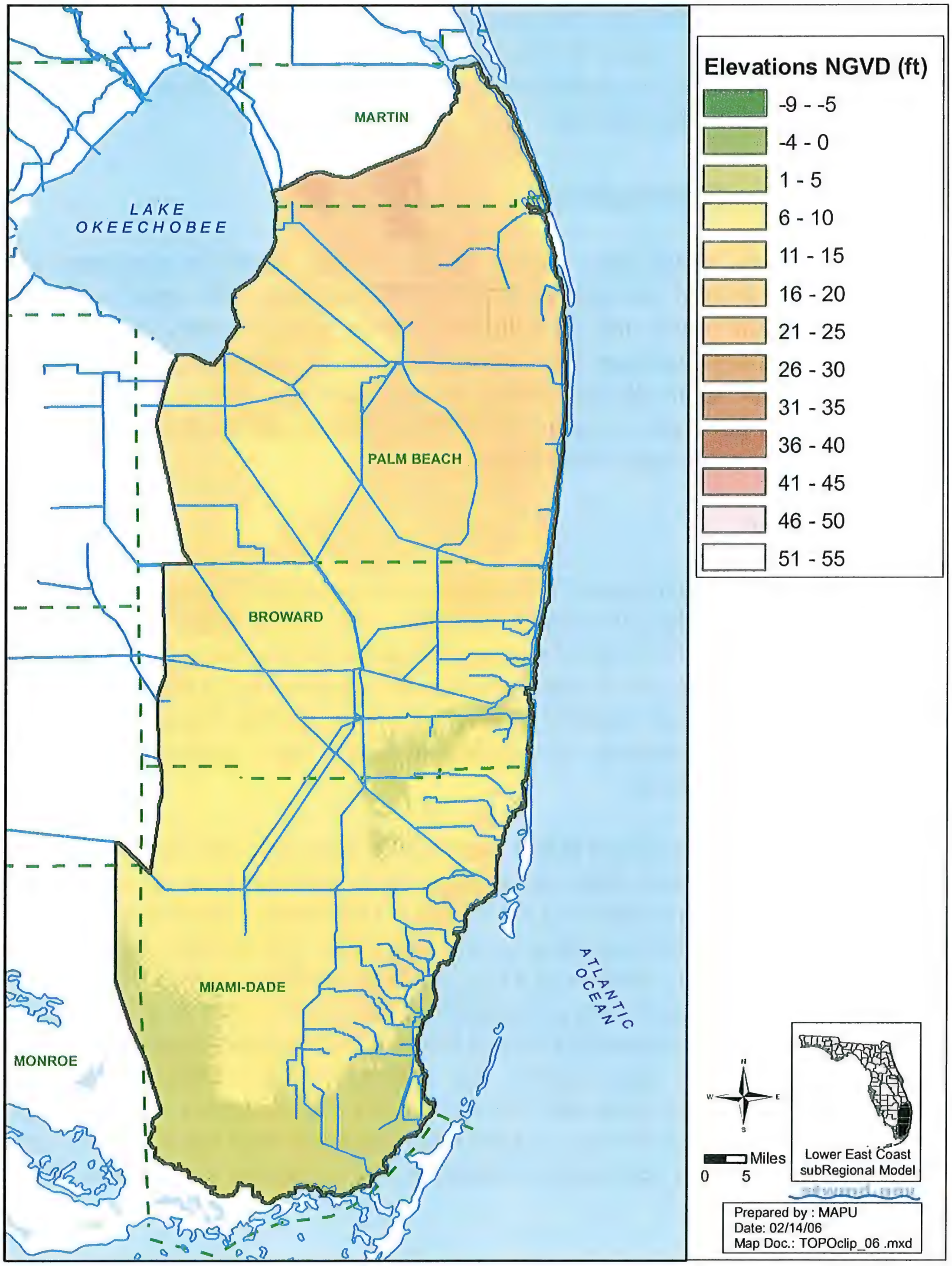


Figure 61. Land Surface Elevations (ft) in the LECsR Model.

Wetlands

Flow within wetlands was modeled using the Wetland Package (Restrepo *et al.* 1998). Wetland areas were identified from 1995 Land Use / Land Cover as shown **Figure 63**. Certain areas that are classified as non-wetlands were selected to maintain contiguous wetland boundaries. This process required some human interaction with the land use data. In the Everglades and Water Conservation Areas, the upland forests (e.g., tree islands) were incorporated in the active wetland boundary. Conversely, small (less than 50 acres) isolated wetlands were dissolved out of the active wetland boundary.

Wetland-Aquifer Interaction

Model layer 1 consists of the wetland flow system (or overland flow regime), underlying soil/muck layer, and all underlying geological strata down to 0 feet NGVD. By incorporating these strata into the wetland flow system, the wetland cells will not become dry and require rewetting. The wetland layer includes ponded water with a specific yield of 0.9; specific yield of the muck/peat is mainly 0.3.

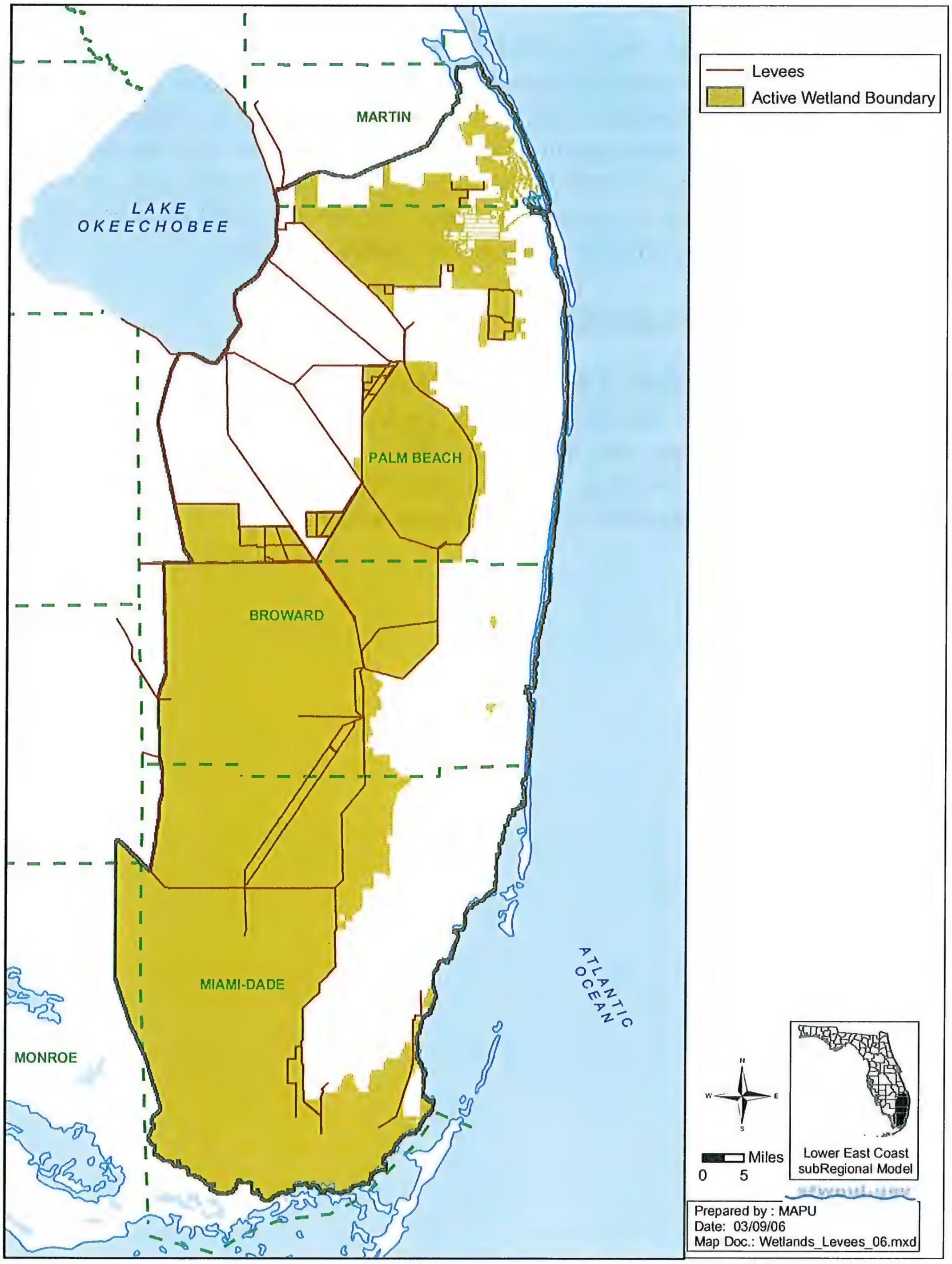


Figure 62. Locations of Modeled Wetlands and Levees.

Wetland-Aquifer Parameters

The data requirements for the wetland model, which are needed to simulate overland flow in wetlands include the following: boundary of wetland areas; elevation of the wetland soil top surface (e.g. derived from land surface); hydraulic conductivity of the muck and aquifer (as a composite), anisotropy ratio, top elevation of the muck, Kadlec coefficient, specific yield of the muck and surface water body; depth of the soil capillary fringe; Kadlec conductance coefficient for overland flow; specific yield of the wetland water body; and coefficients α and β for the Kadlec equation (e.g., as derived using the Manning equation).

The Kadlec coefficient is assigned to each cell based on the land use or vegetation type. The suggested values were not derived from field data; they were obtained during model design. Numerical difficulties may result when a K larger than 1 million is used. However, the model was assigned high K's where appropriate (e.g., open water, sloughs). The highest K in the model is $2.0x10^6$ ft2/day/ftβ and was applied to wetland areas with sparsest vegetation (i.e., along the southern tidal boundary). A lower bound was established based on the highest estimated K ($2.0x10^6$ ft2/day/ftβ).The lower bound is 20 percent of the maximum K and was applied to wetland areas covered with the most dense vegetation. The upper bound describes flow exhibiting less friction and a higher velocity while the lower bound describes flow of a higher resistance. All other types of wetland classes were assigned a value of hydraulic conductance between the two extremes. An exponential function was used to compute K to interpolate values from the upper and lower bound.

Surface Water Management

A combination of packages was used to manage or handle surface water flows in the model. In combination, the Wetland, Diversion, and Reinjection Flow Packages can work together to simulate non-Darcy flow, operational schedules, management rules, and simple, lumped routing of sub-basin flow downstream.

Rivers and Drains

MODFLOW requires a canal conductance to compute the flux to or from the aquifer. Hydraulic canal properties (i.e., cross-sections) were used to estimate river and drain conductances. Primary and secondary canal networks were derived from the previous subregional models for North Palm Beach, South Palm Beach, Broward, and South Miami-Dade. Additional missing or misplaced canals were identified from satellite and aerial photos. Canal dimensions were obtained from typical cross-sections in permits. As in several cases where no or suspect data existed, field transect measurements were made across the canals to obtain the required canal dimensions. Controls for some agricultural areas had to be estimated from topography and known operational procedures for the crop being grown (ie canals are maintained two feet below

ground surface for optimal growing conditions). The final canal network used for model design is shown in **Figures 63 to 67**.

The three main categories used to represent the canal network include canals as rivers, drains, and flows. Canals were assigned as rivers when the control elevations change over time and water is delivered from the regional system (i.e., external source). Most of the canals in the model act like rivers. Canals were specified as drains when controls do not change over time (e.g., weir). The last category assigns canals to the RDF and Diversion Packages in order to route canal flows downstream.

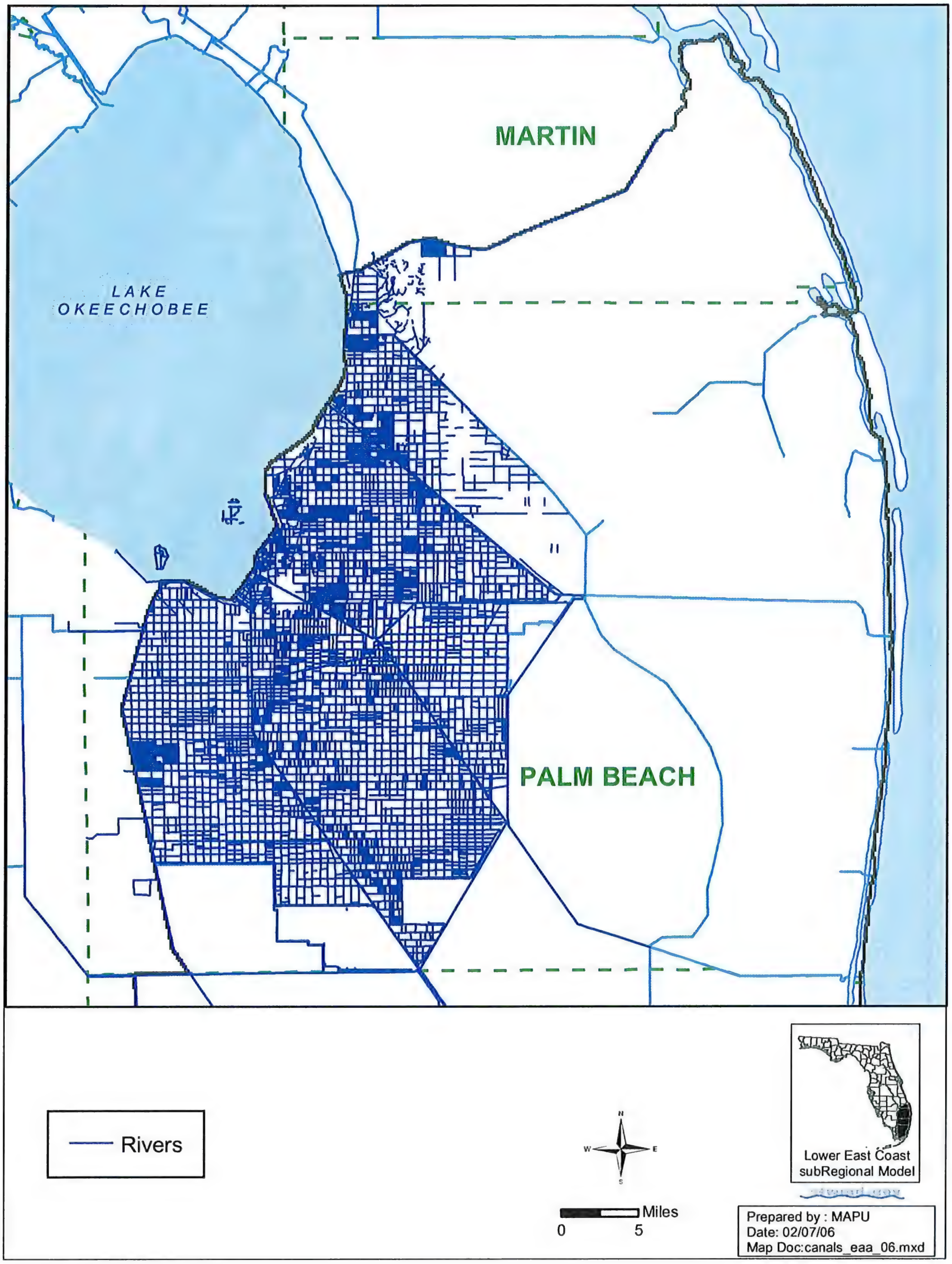


Figure 63. EAA Canals

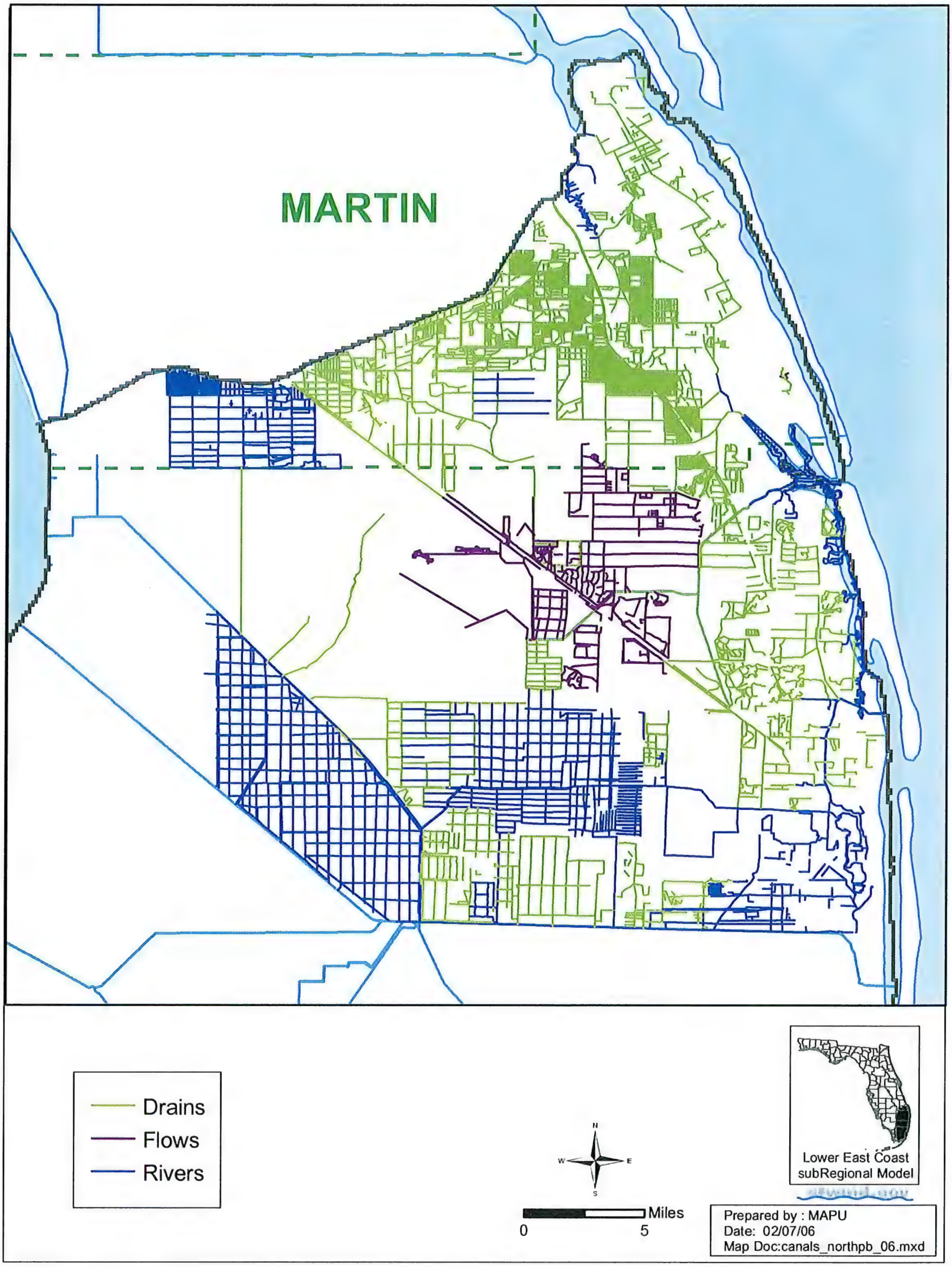


Figure 64. North Palm Beach Canals

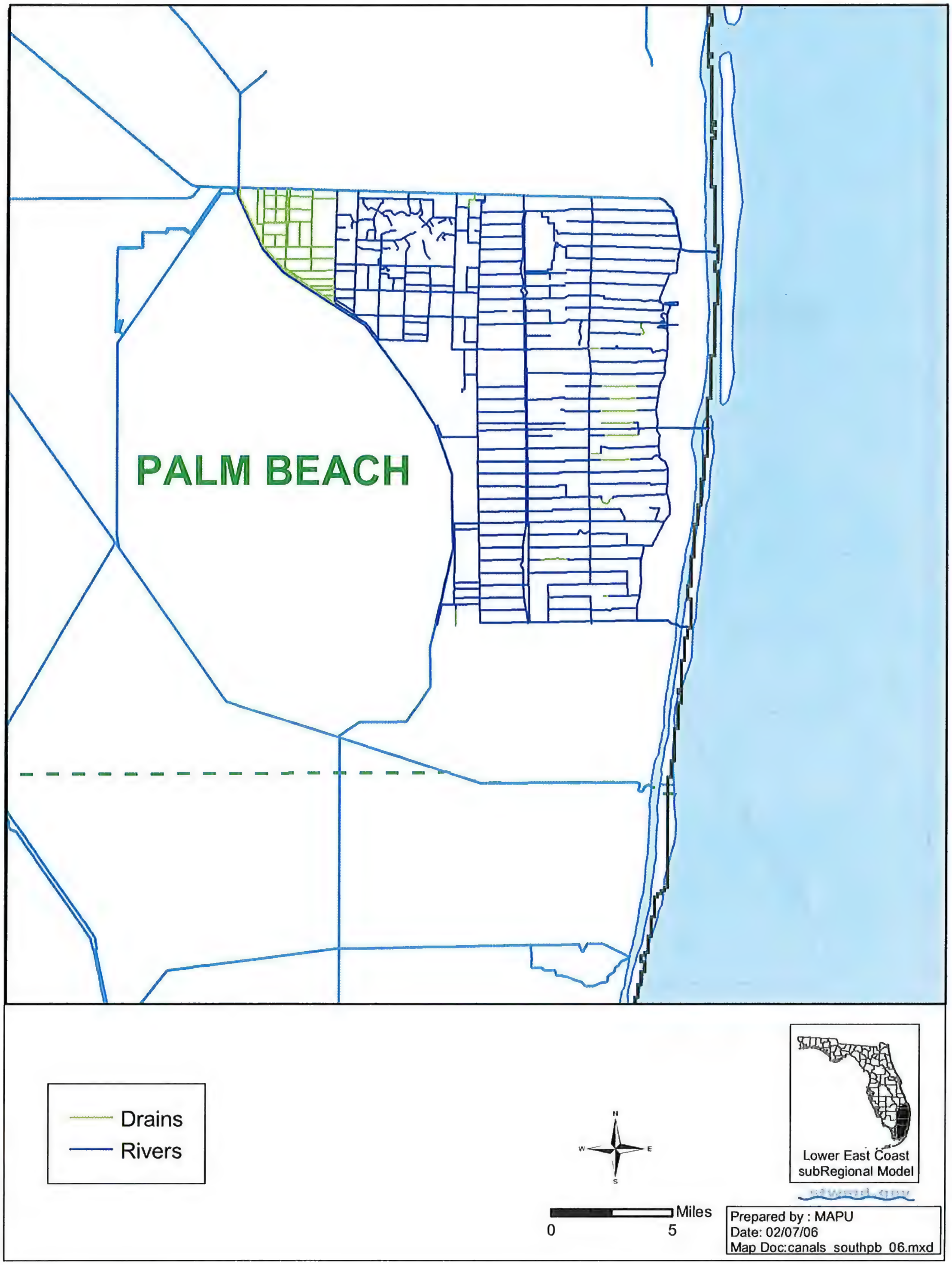


Figure 65. South Palm Beach Canals

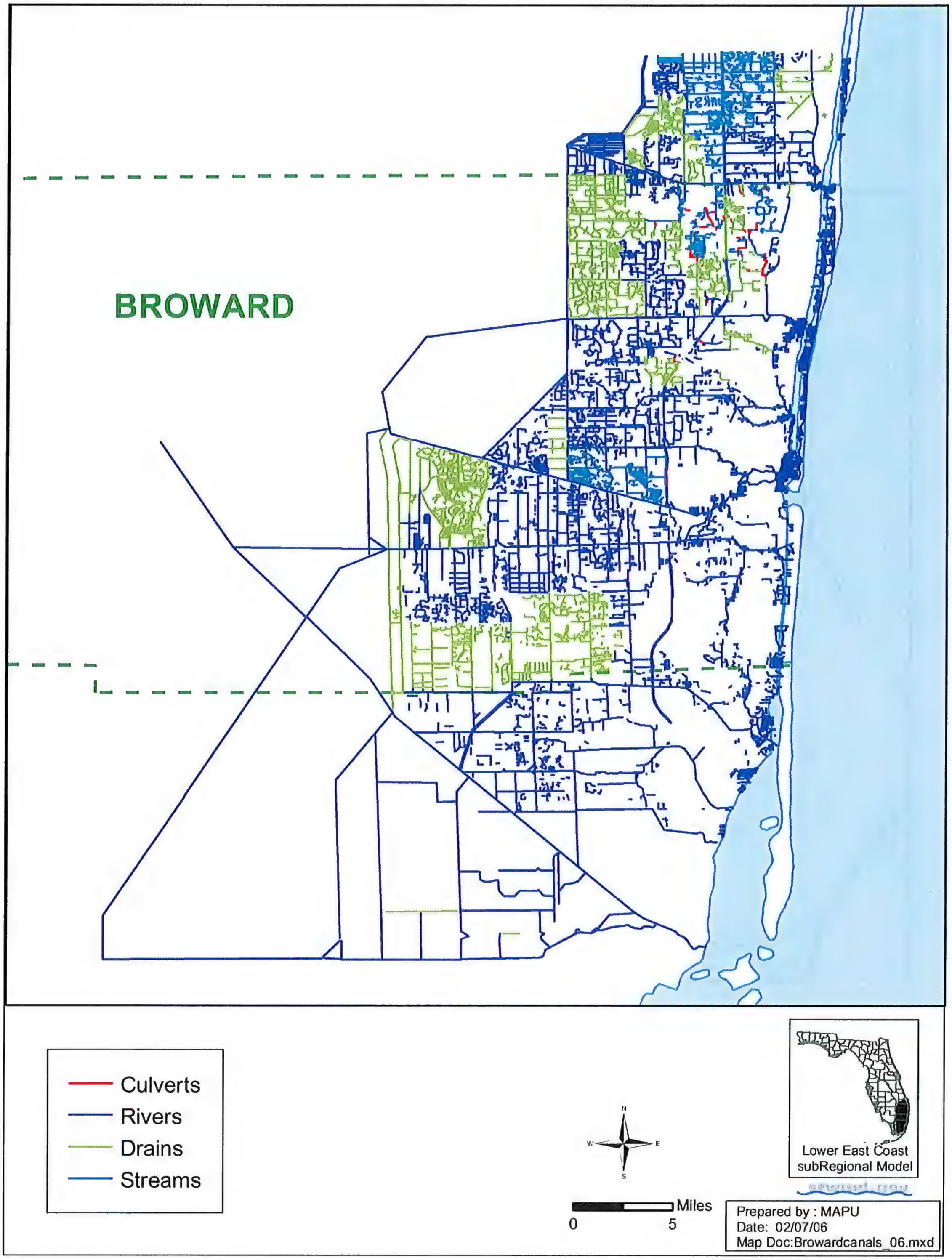


Figure 66. Broward Canals

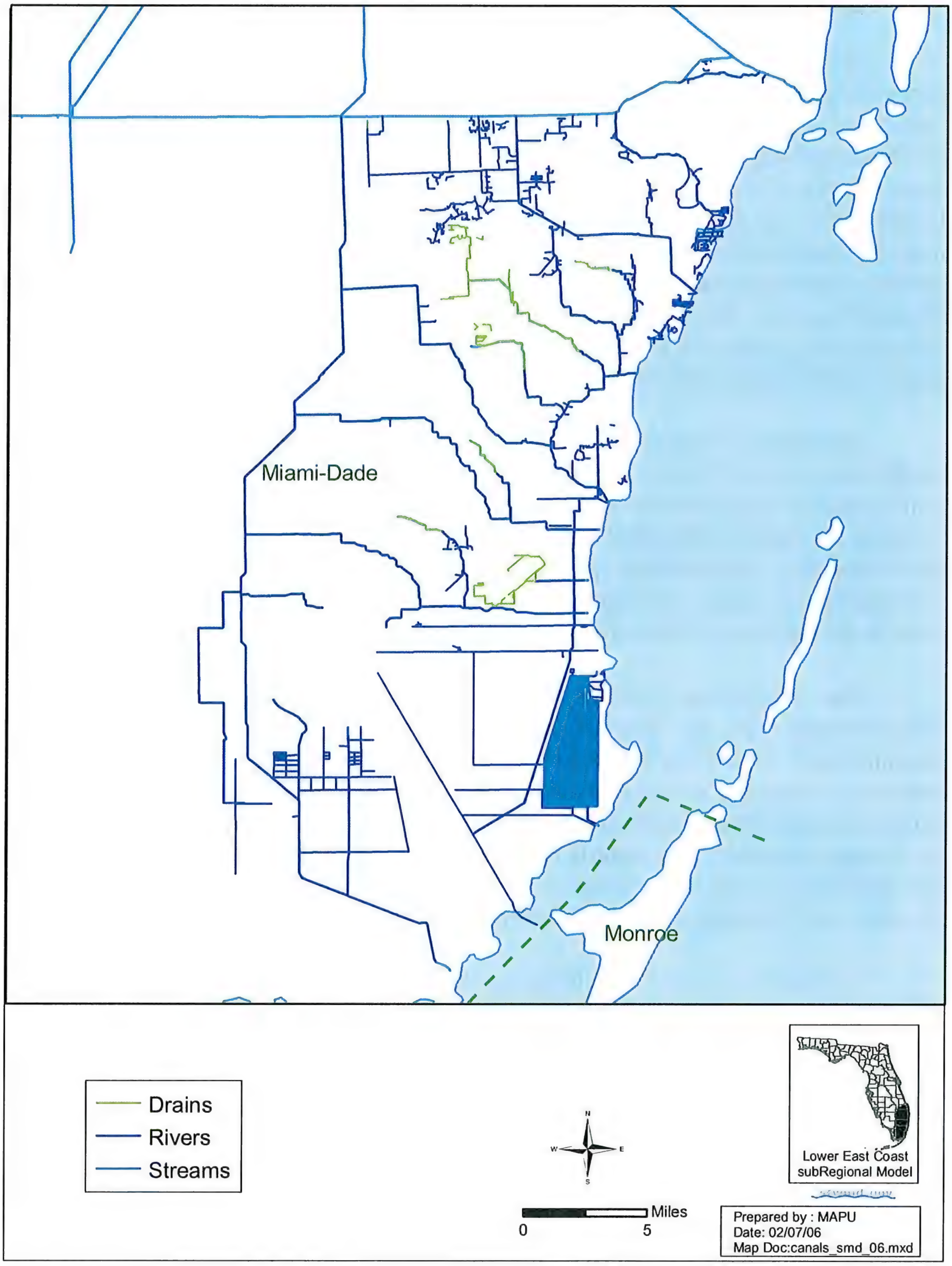


Figure 67. South Miami-Dade Canals

Water Deliveries in LECsR

The Water Conservation Areas operated by the SFWMD are, for all practical purposes, above ground impoundments. They are completed surround by a levee system and water is moved into them, through them and out of them to meet both urban and environmental demands as well as a place to provide storage during wet periods. Each compartment is regulated with an upper limit to protect the levees from breaching. Lower limits are also addressed in some areas for environmental concerns. However, they do occasionally dry out and wildfires are not an uncommon occurrence. Another above ground impoundment is the West Palm Beach Water Catchment Area, or Grassy Waters Preserve. This impoundment stores water for the City of West Palm Beach and utilizes surface water for its water supply. Most of the time, the Catchment Area does not receive water supply deliveries from Lake Okeechobee.

Simulation of above ground impoundments is accomplished primarily through a combination of the Wetland package and the Diversion package. Grassy Waters Preserve will be used to illustrate how these facilities are simulated. The cells that Grassy Waters Preserve are initially identified and assigned as wetland cells. The levee system (i.e., top elevations) that surrounds the impoundment is added to the topography in the wetlands. The higher topography associated with the levees ensures that water does not overland flow to the adjacent cell that are also wetlands but not part of the impoundment.

The Diversions Package is required to move water into and out of the impoundment. In the case of Grassy Water Preserve, water is brought into the impoundment from Lake Okeechobee which is outside of the model domain. The structure component of the Diversion package allows for the assignment of an outside source to ensure that mass balance is preserved. Water is moved into the facility, up to the volume specified. The criteria in this case are that the water level must be below 18.9 feet NGVD at each cell. Water is then removed from the impoundment utilizing the standard well package at historical water withdrawal rates.

Inflow from Lake Okeechobee to Water Conservation Areas 1A, 2A and 3A are done similar to Grassy Water Preserve however, outflows to the urban areas and movement through the various compartments is accomplished in a slightly different manner. The net flow for a conservation area is equal to the Lake Okeechobee inflows minus the urban outflows. If the Lake Okeechobee inflows are greater than the urban area outflows the net volume for the Conservation area will be positive indicating that water is entering the WCA, if it is negative then water is being removed from the impoundment. This is done for each individual day of the simulation period. Urban outflows from Water Conservation Area 1 are primarily to the Lake Worth Drainage District, Broward County and the City of Boca Raton.

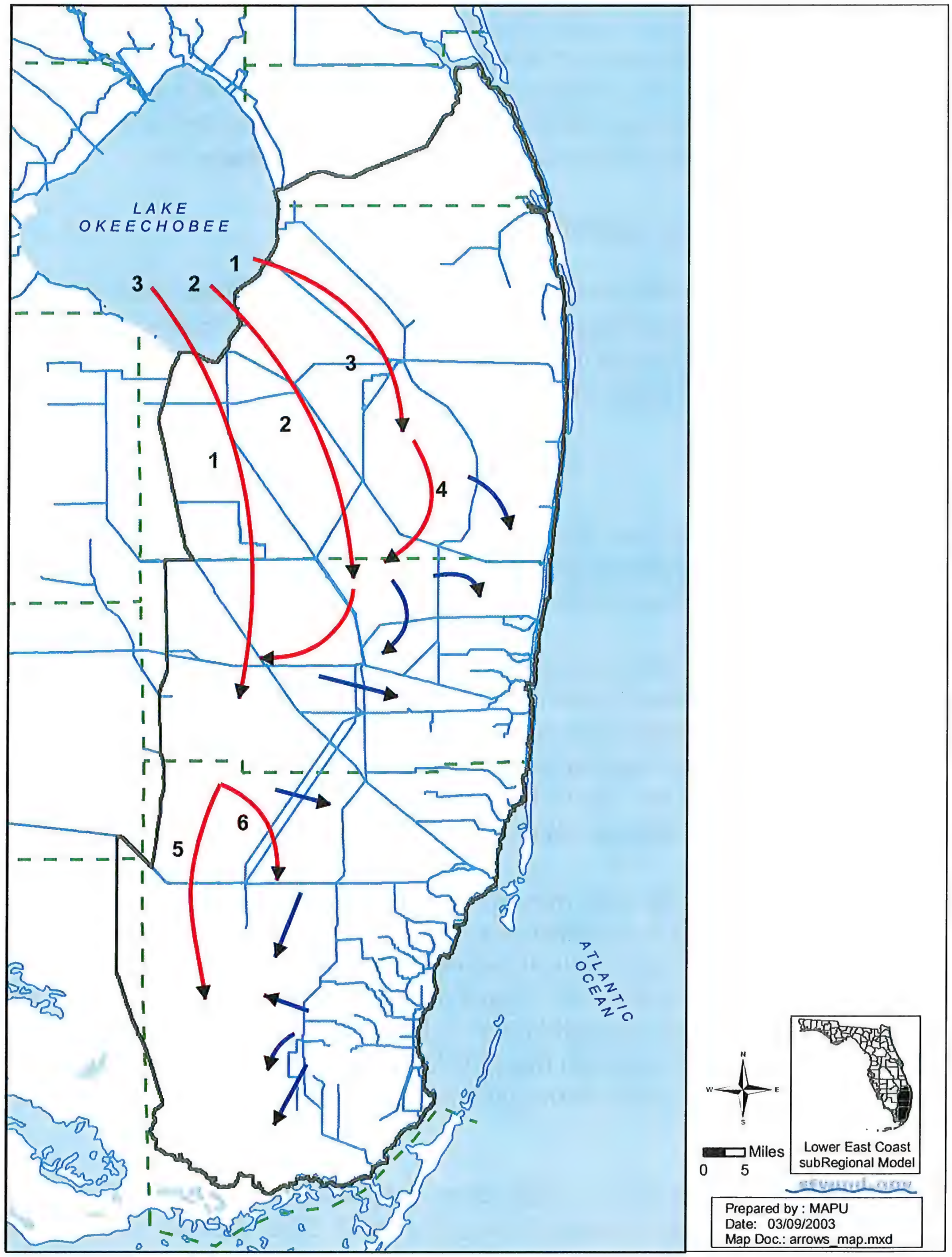


Figure 68. Modeled Surface Water Management Features.

Boundary and Initial Conditions

Model boundary definition is an important consideration during model design, since boundaries can affect flow patterns. In order to minimize errors in model

simulation, two principles were followed to define the type and placement of boundaries: 1) the observed physical system dictated the type of boundary conditions employed, and 2) where possible, placement of model boundaries was made at great distances from the areas of interest in order to reduce the boundary effects upon the simulation results. This resulted in a series of general head boundaries (apart from the no-flow inactive cells) being applied throughout all model layers as depicted in **Figure 70**.

Outer Boundary Conditions

According to McDonald and Harbaugh (1988), a general head boundary consists of a water source outside the modeled area that supplies or removes water to a model cell at a rate proportional to the head difference between the source and the active cell. The rate at which water is supplied to a cell is given by:

$$Q = C(H_s - h_c) \qquad \textbf{Equation 3}$$

where Q is the flow rate (ft^3/day) to or from the cell from the boundary and C is the constant of proportionality boundary. H_s is the average head at the source boundary and h_c is the average head in the cell.

The General Head Boundary (GHB) Package is applied at all of the cells located along the LECsR Model boundary. As described in Chapter 2, the study area was delineated by hydrologic and hydrogeologic boundaries. Surface water stages define the northern and western boundaries. The eastern and southern boundaries are defined by modeled tidal elevations. The GHB Package was chosen so that the conductance could be calibrated along the saltwater interface and boundary conditions could vary with time.

Boundary conditions were applied to the model by identifying several stations (**Figure 70**). Historical or modeled water levels were applied to a section of cells. For instance, historical water levels at station, S-80_HEAD were assigned to over 100 cells representing the upstream canal stages in C-44. Modeled tidal elevations were derived from the hydrodynamic model, WNAT (Hagen 2005). Modeled data was preferred over the limited historical, tidal data from NOAA. The modeled tidal data characterize the best representative daily value while minimizing the number of stations used in the GHB Package.

Surface water stages include those along the C-44, L-24, and L-28 Canals. All of these stages are applied to model layers 1, 2 and 3. Since the aquifer is unconfined, there is a good connection between the aquifer and canal stages. In the case of C-44, this canal acts like a groundwater divide in which groundwater flow from the north and south is intercepted by the canal. The other two canals, along the western boundary, are located in a region with low hydrologic stresses (e.g., no pumping wells). This region is also near to a regional groundwater divide.

The eastern and southern boundaries of the LECsR Model Area follow the Intracoastal Waterway, Biscayne Bay, and Florida Bay. Modeled tidal elevations are defined by four sections in this area. Initially, astronomic tides were generated for 134 locations. Individual locations were grouped into sections based on similarities in tidal range, phase, and composition (Hagen 2005).

Sections 1 to 4 are within close proximity to the saltwater interface. The density correction option in the UGEN Package is activated in order to compute equivalent fresh water heads for these cells during model execution. The following formula was used to calculate the vertical pressure distribution along the boundary of the freshwater heads:

$$H_{eq} = (H_s - L_e)(\frac{\gamma_s}{\gamma_f} - 1) + H_s \qquad \textbf{Equation 4}$$

Where H_{eq} is the equivalent freshwater head at the boundary; H_s is the tidal stage; L_e is the elevation within the aquifer where the equivalent freshwater head is to be applied; γ_s is the specific weight of salt water and γ_f is the specific weight of freshwater. If L_{eb} is -320 ft, the equivalent freshwater head for a tidal elevation, H_s of 2 ft is 2.3 ft when L_e is -10 ft and γ_s and γ_f are 1.021 and 1.0, respectively. The equivalent freshwater head for the same tidal elevation at a depth, L_e of -70 ft is 3.5 ft (holding all above assumptions true). When Le is -220 ft, NGVD, the equivalent freshwater head is 6.6 ft. This case (**Figure 69**) illustrates that when equivalent freshwater head is computed at depth there is an upward vertical gradient, which is expected along the saltwater interface.

Prior to model execution, conductances are computed as input to the GHB Package. In order to avoid large vertical flows at the boundary while mimicking the natural processes at this location, the following scaling factor was applied to the conductance values along the tidal boundary:

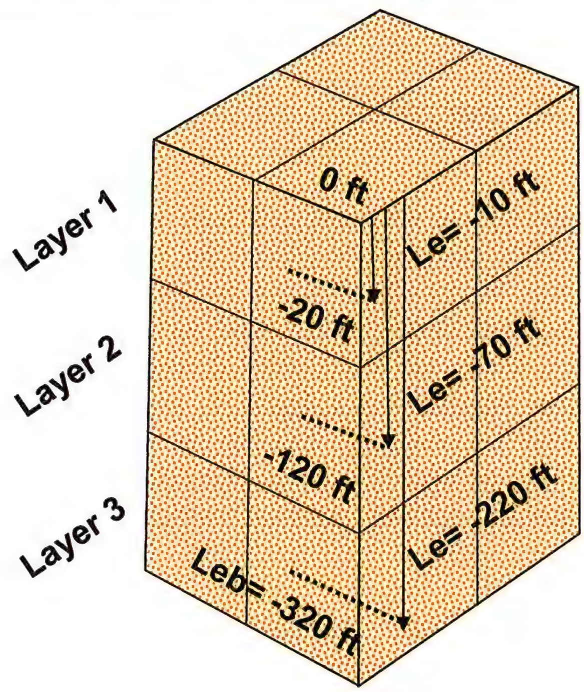
$$Sc = \left[\frac{(H_s - L_e)}{(H_s - L_{eb})} - 0.7\right]^2 \times 3 \quad \textbf{Equation 5}$$

where Sc is the scaling factor and L_{eb} is the elevation of the Surficial aquifer system base at the node center. The concept of the scaling factor was applied by Restrepo *et al.* 2001, Wilsnack *et al.* 2000, and Nair *et al.* 2001 in previous mulit-layered groundwater models. The factor is applied to all GHB cells in layers 1 to 3 to approximate reduced flows from the saltwater interface into the aquifer at depth. In the upper layers of the model, the factor facilitates the upward movement of flow from the deeper layers. The movement of freshwater upward along the saline interface toward the near surface strata is consistent with previous studies ((Kohout 1964) and Geotrans 1988)). Since MODFLOW assumes a constant density of water, the scaling factor reflects the assumption that the saltwater interface is fixed in time and space. **Table 9** shows the average conductance for each station and for each layer.

Table 9. Representative GHB Conductance for Modeled Tidal Stations.

Model Layers	SECTION1	SECTION2	SECTION3	SECTION4
1	2.0E+04	2.3E+04	4.3E+04	2.9E+04
2	1.6E+05	7.7E+05	9.0E+05	6.7E+05
3	3.9E+04	1.2E+03	1.6E+02	9.8E+02

Figure 69. Diagram of Model Layer Used to Compute Head at Depth.



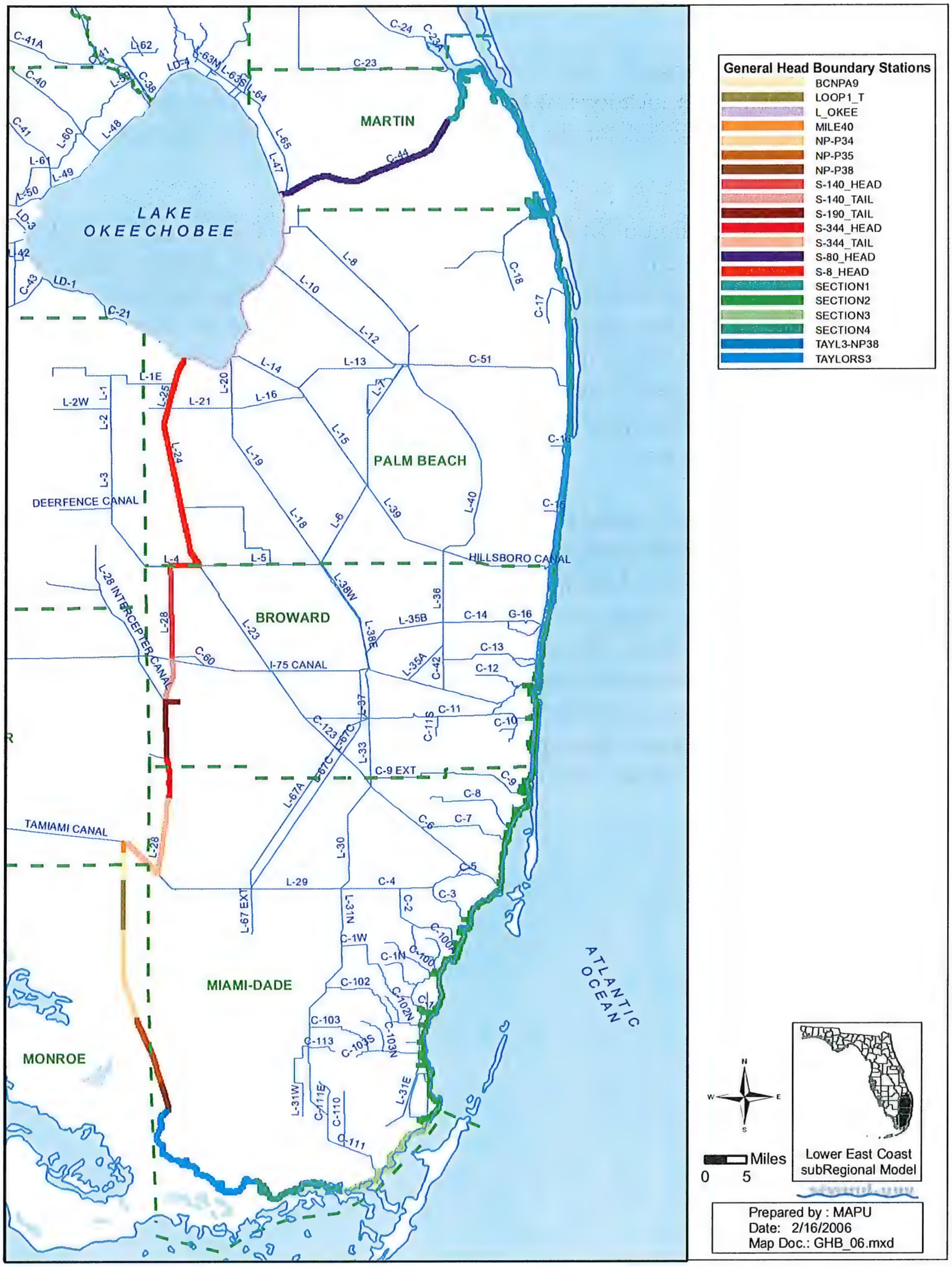


Figure 70. Location of Active Model Area and General Head Boundary Stations.

Initial Conditions

Transient models require initial conditions which are boundaries in time. These conditions are given at all locations in the model prior to model execution. In this case, initial conditions are provided for the three model layers and are representative of the water table.

The SFWMD version of MODFLOW-96 was developed for transient conditions; therefore, the user is prevented from executing a steady-state run. During initial model design, initial water table elevations were approximated by reducing the topography by 2 ft in each model cell. The same initial conditions were used in every layer. The justification is that the aquifer is unconfined and the water table is shallow and close to land surface in many places. It was observed that in higher relief areas (e.g., coastal ridges) the initial conditions were too high and in lower relief areas (e.g., marshes) the initial conditions were too low.

The initial conditions were then improved upon by applying pseudo-steady-state conditions. A pseudo steady-state run is one that achieves steady-state conditions by repeating (daily) stresses for a length of time. The initial conditions based on the lowered topography were used as input to a pseudo-steady-state run. All packages with time-varying heads or flows were set up to repeat the first stress period. For example, if a well pumped 200 cfs in the first stress period, this value was repeated for the next 10 stress periods. Pseudo-steady-state conditions were applied for 10 stress periods. The resulting heads for layers 1 to 3 were then applied as initial conditions to a second run. This process was repeated once more with those results being used in the model at the present time (**Figure 71**).

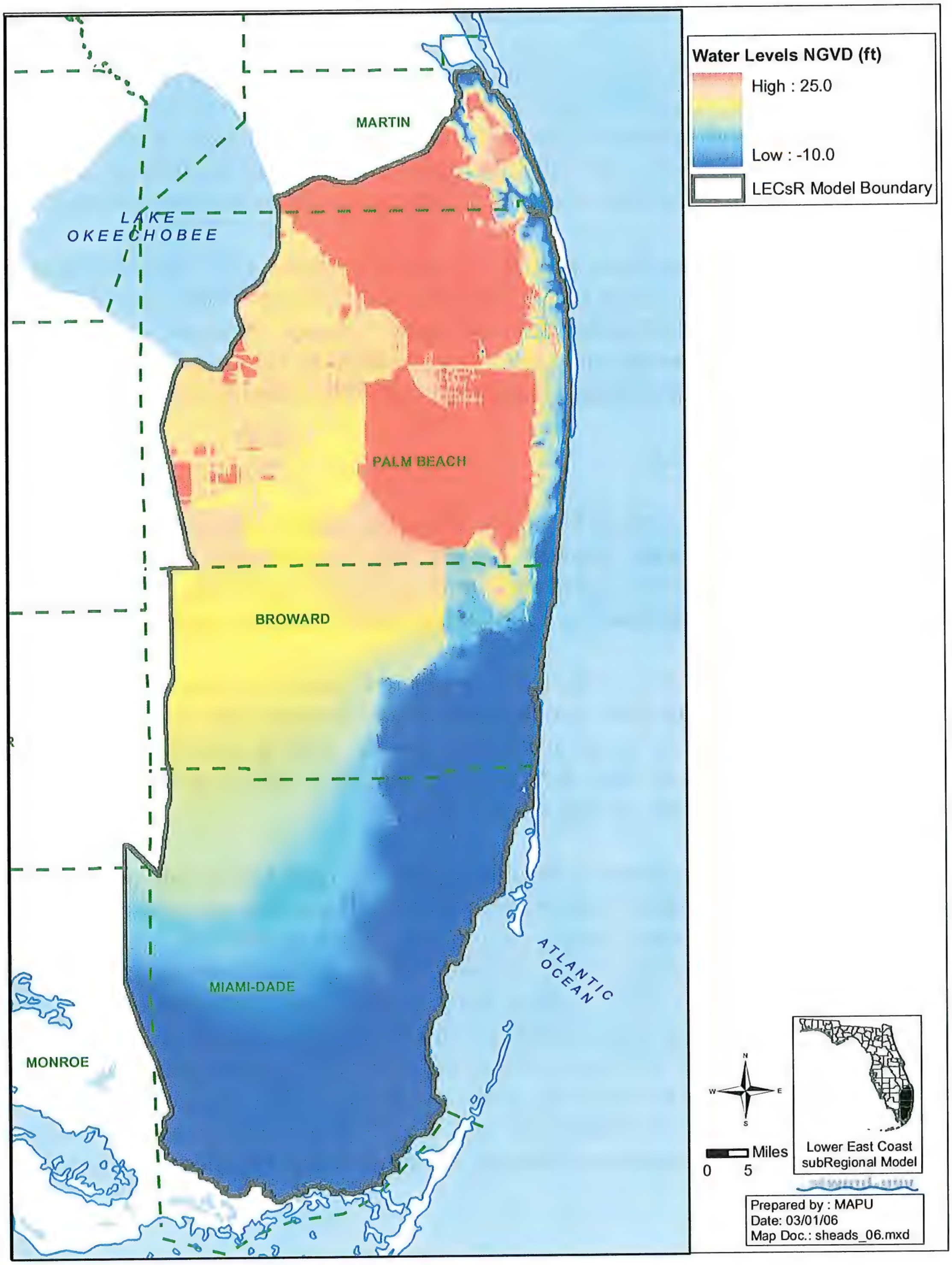


Figure 71. Initial Conditions (ft NGVD) in Model Layer 1. Stretched to 1 Standard Deviation.

Evapotranspiration and Recharge

The calculation of maximum potential evapotranspiration (ET) rate in the LECsR is based on reference crop ET which is adjusted according to crop type, available soil moisture content, and location of the water table. Algorithms used to calculate actual evapotranspiration vary geographically because of different data availability, and varying physical and operational characteristics of different areas within the model domain.

Recharge and maximum potential evapotranspiration (ET) rate time series are computed using an ET-recharge model (Restrepo and Giddings 1994). The methodology is based on a daily unsaturated/saturated water balance approach on each unique combination of land cover and soil type. This model is an extension of the Agricultural Field-Scale Irrigation Requirements Simulation (AFSIRS) Program (Smajstrla 1990).

ET-Recharge Model

In the LEC and Everglades areas, irrigation supply, unsaturated zone ET and recharge into the Surficial Aquifer System are preprocessed, i.e., pre-calculated quantities, and used in the unsaturated zone moisture accounting. These quantities, among others, were output from the ET-Recharge model (Giddings and Restrepo 1995).

The unsaturated zone is treated as a separate control volume where infiltration, percolation, evapotranspiration and changes in soil moisture are accounted for. The reasons for the unsaturated zone accounting are the need to quantify LEC irrigation applied to the unsaturated zone and to more accurately assess changes in irrigation requirements associated with changes in land use.

The ET-Recharge model is based on Land Use/ Land Cover, soil, and a reference table for each unique land use and soil type area in relating land use classification to the following: runoff coefficients; crop type; growing season; percent pervious area; switch indicating if area is irrigated or not; and water use type classification. As outlined in Restrepo and Giddings (1994), a daily water balance was conducted on each unique combination of land cover and soil type. A corresponding maximum evapotranspiration rate was assigned to each of these combinations. The daily water balance analysis yields the amount of recharge to the water table that is input into the model. The ET and recharge values that were developed this way were held relatively constant in the model throughout the calibrations process. **Figure 72** shows the distribution of recharge in the model area.

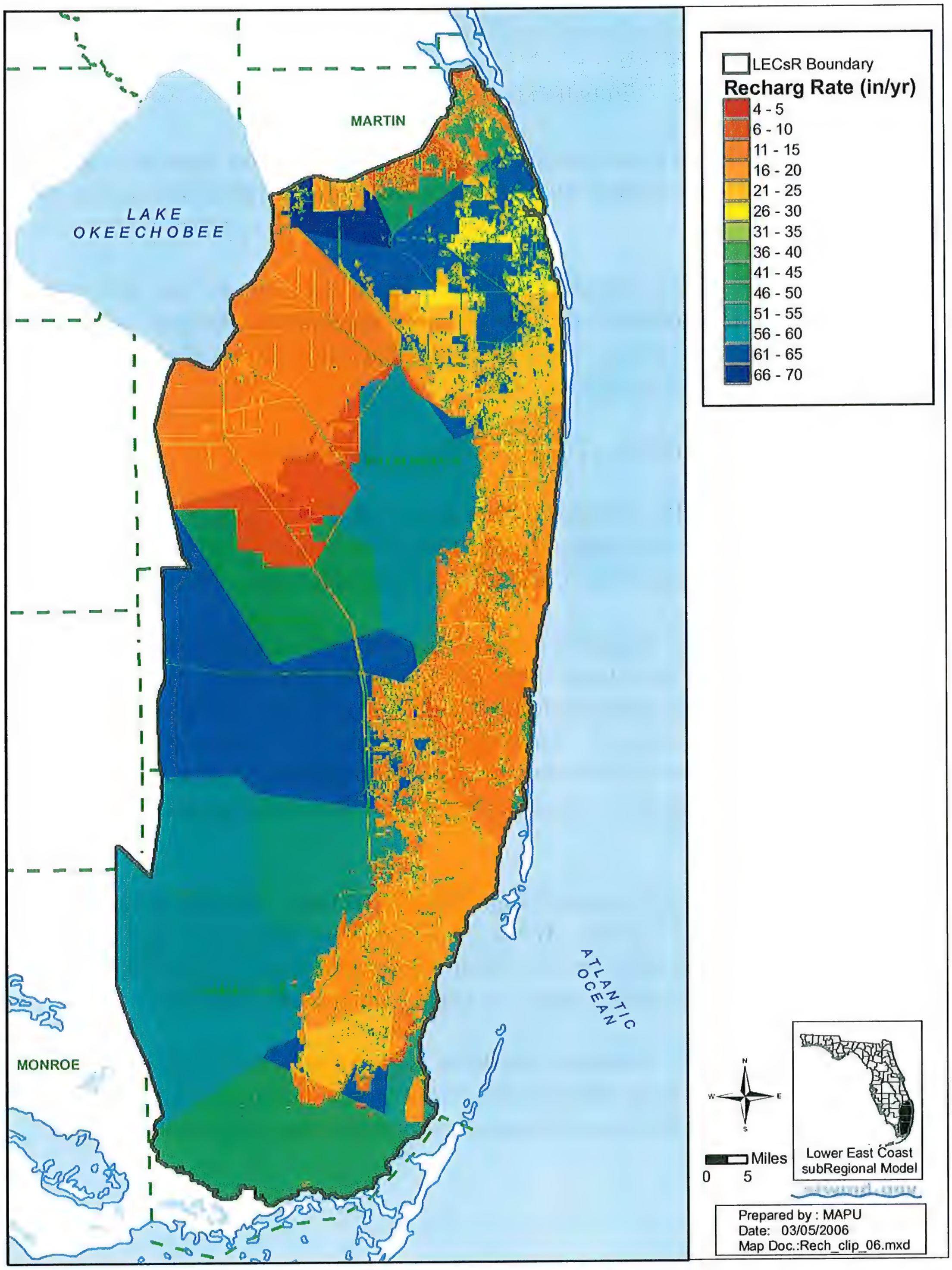


Figure 72. Average Annual Recharge Rate in inches/year (1986-2000)

Daily rainfall and wet marsh potential ET are defined as inputs to AFSIRS. AFSIRS calculates the crop potential evapotranspiration (ET_p) using the formula:

$ET_p = K_{crop}ET_r$ Equation 6

where K_{crop} is the crop coefficient that varies with crop type and crop growth stage, and ET_r is the wet marsh potential ET (see wet marsh potential ET section for more details).

The rate at which water is returned from the soil to the atmosphere by evapotranspiration is controlled by two factors: atmospheric demand and soil-water availability (Jensen *et al.* 1990). For a pervious area, AFSIRS is called to perform crop root zone water balance on a daily basis:

$\Delta STO = RAIN + NIRR - DRAIN - ET$ Equation 5

Where ΔSTO is the change in root zone soil water storage, (in); RAIN is the rainfall (in); NIRR is the net irrigation requirement or irrigation supply (in.); DRAIN is the drainage and surface runoff (in.); and ET is the evapotranspiration (in).

AFSIRS calculates irrigation requirements and crop evapotranspiration rates as a function of crop type, soil type, irrigation system, growing season, and climatic conditions. It assumes that crop requirements are met from the unsaturated zone through rainfall or supplemental irrigation. An irrigation management option within AFSIRS was selected such that the exact amount and timing of the irrigation is to be used to restore the root zone to field capacity (i.e., maximum yield and thus, maximum or potential ET is always maintained).

Irrigation deliveries calculated from the ET-Recharge model are treated as target irrigation demands in the LECsR. These irrigation demands can be met from various sources (mainly the water table but also from wastewater reuse and public water supply) and are the basis for implementing the LEC trigger and cutback modules.

The calculation of maximum potential evapotranspiration (ET) rate in the LEC and Everglades areas can be partitioned into non-irrigated and irrigated areas as explained below. **Figure 73** shows landscape irrigated and non-irrigated areas in the LECsR.

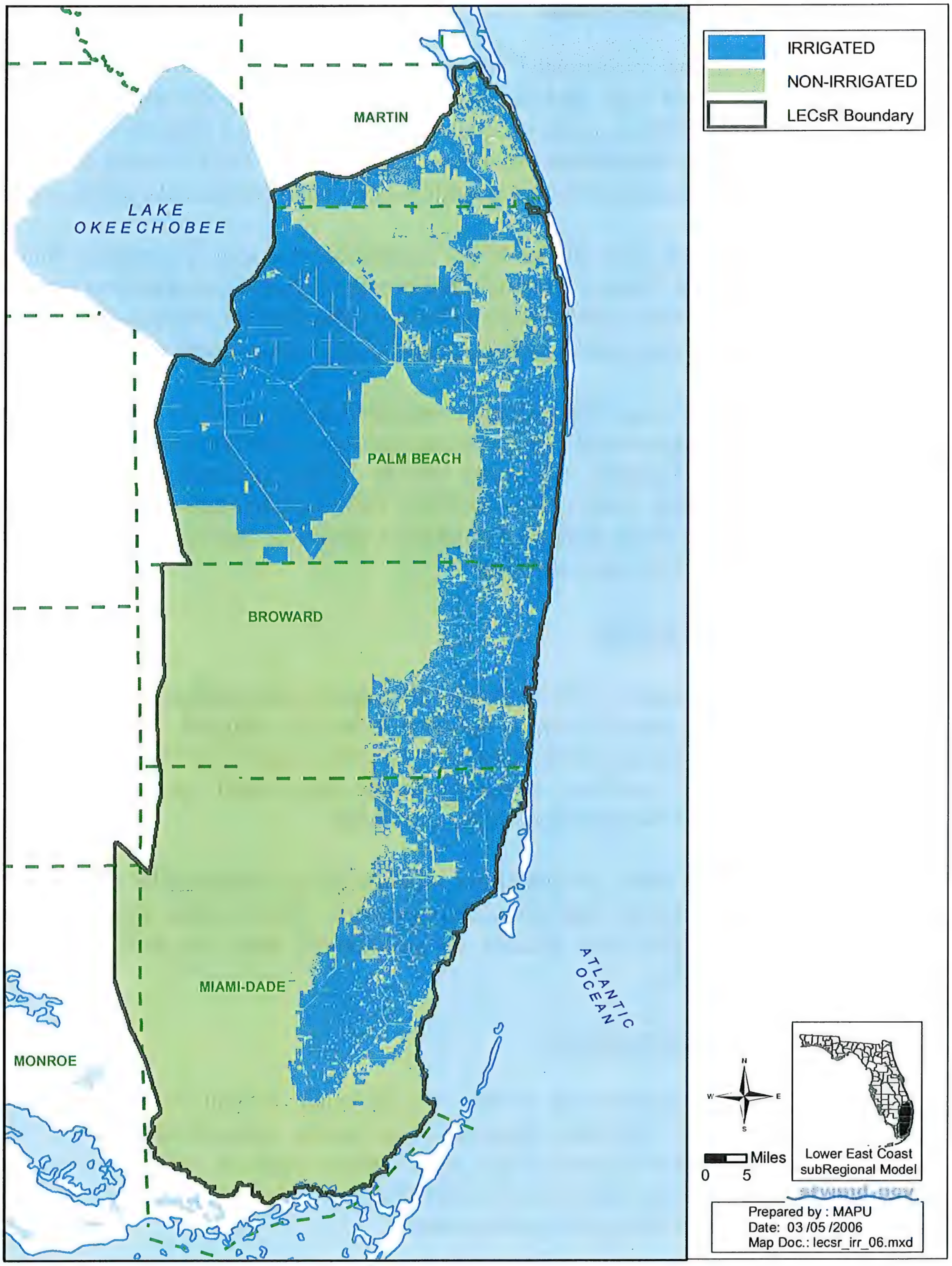


Figure 73. Irrigated and Non-Irrigated Areas in the LECsR Model.

ET in Non-irrigated Areas

Vegetation in the non-irrigated vegetated areas of the LEC utilizes the available water in the unsaturated zone and supplements demands from the water table when possible. This implies that as water is used up in the unsaturated zone by the plant, the plant develops a greater dependency from the saturated zone. The ET in the unsaturated zone approaches zero during a deficient rainfall period due to reduction in soil storage.

For non-irrigated areas in the Water Conservation Areas, Everglades National Park and portions of Big Cypress National Preserve, the following assumptions are made: (1) moisture content between land surface and water table does not change; (2) ET comes only from the saturated zone and/or ponding; and (3) infiltration equals percolation.

In the saturated zone, the maximum saturated ET is equal to the supplemental crop demand. The supplemental demand is equivalent to what the crop needs from the water table once the available soil water storage in the unsaturated zone has been depleted. In groundwater models (e.g., MODFLOW), the maximum saturated zone ET rate is a linear function of the distance from the ET surface to the water table and on the extinction depth applied for a specific crop.

ET in irrigated Areas

The ET which occurs in the irrigated LEC areas is computed essentially equal to the ET for the crop because the crop is assumed to be well irrigated. This implies that water is removed from the saturated zone at a rate equal to the ET for the crop. If the ET rate exceeds the water available in storage in the unsaturated zone, then, water is provided to the plant via the irrigation system or rainfall.

In the saturated zone, the maximum saturated ET is computed by the difference between the potential crop ET and the unsaturated zone. The saturated zone ET is equal to zero for well irrigated areas because the unsaturated zone can meet all the crop demands due to irrigation.

Deep Percolation Rates

The deep percolation zone is the zone in which rainfall or excess irrigation reaches the aquifer and provides direct recharge to the groundwater system. It is calculated as the residual function of the water balance equation within the root zone. Due to excessive recharge rates, runoff coefficients are utilized to reduce percolation rates for irrigated and non-irrigated pervious areas.

Wet Marsh Potential Evapotranspiration

The SFWMD Simple Method (Abtew 2003) was used to provide estimates of long-term historical (1965-2000) wet marsh potential ET for long-term hydrogeological modeling as described in Irizarry-Ortiz (2003). The SFWMD Simple Method was developed as a modification to the Penman-Monteith formula due to the lack of a comprehensive meteorological database for south Florida. The LECsR Model used the estimated wet marsh potential ET for the years, 1986-2000.

Wet marsh potential ET, ET_p (mm d-1), is computed as:

$ET_p = K_1 \; R_s / \lambda$ Equation 1

Where K_1 is a coefficient; R_s is the solar radiation received at the land surface (MJ m-2 d-1); and λ is the latent head evaporation (MJ kg-1).

Potential ET is defined as "the rate at which water, if available, would be removed from saturated soil in the form of latent head per unit area or the equivalent depth of water" (Restrepo and Giddings 1994). Due to the difference in roughness characteristics between marsh and reference grass surfaces, the crop coefficients developed with respect to a grass reference ET needed to be modified for use with wet marsh potential ET.

Due to the scarcity of solar radiation and cloud cover data, solar radiation (Rs) was estimated as a function of atmospheric transmissivity, temperature, and extraterrestrial solar radiation (Irizarry-Ortiz 2003).

Extraterrestrial solar radiation is calculated from latitude and time of year by integrating the instantaneous radiation intensity at the outer atmosphere from sunrise to sunset. The potential ET for wetland marsh was calculated and applied at 17 NOAA stations with long-term daily temperature data in order to provide estimates of Rs for hydrogeologic modeling. Annual time series and summary statistics of wet marsh potential evapotranspiration estimated at 17 NOAA stations are presented in **Appendix A**. The Inverse Distance Weighting method was used for spatially-interpolating the wet marsh potential ET across the LECsR grid.

Evapotranspiration Package in MODFLOW

The ET Package uses the following input data:

- An ET surface array depicting the elevations at which evapotranspiration from the water table occurs at a maximum rate.
- An array of maximum ET rates.
- An array of extinction depths that represent the water depths below the ET surface where evapotranspiration rates from the water table become negligible.

The generalized form of the ET function in MODFLOW is (McDonald and Harbaugh 1988):

$$ET_{sat} = K_{fact}\ ET_{sat\text{-}max} \qquad \text{Equation 7}$$

where ET_{sat} is the saturated ET rate (inches/day), K_{fact} is an adjustment factor, and $ET_{sat\text{-}max}$ is the maximum potential saturated ET (inches/day).

K_{fact} or extinction depth varies linearly from ET surface array (ground surface) to the bottom of the shallow and deep root zone. This factor is used to simulate the diminishing ability of vegetation to use water and is function of vegetation/crop type and water table.

The $ET_{sat\text{-}max}$ rate is computed by the difference between the potential crop ET, ET_P, and the unsaturated zone (ET_{unsat}). These quantities, among others, are output from the ET-Recharge model (Giddings and Restrepo 1995). The ET Recharge Model outputs the daily $ET_{sat\text{-}max}$ rate. **Figure 74** displays the annual average $ET_{sat\text{-}max}$ rate. Rates in the EAA and other agricultural areas appear lower than expected. The reason for this is that AFSIRS is accounting for the water removed from the unsaturated zone due to crop water requirements.

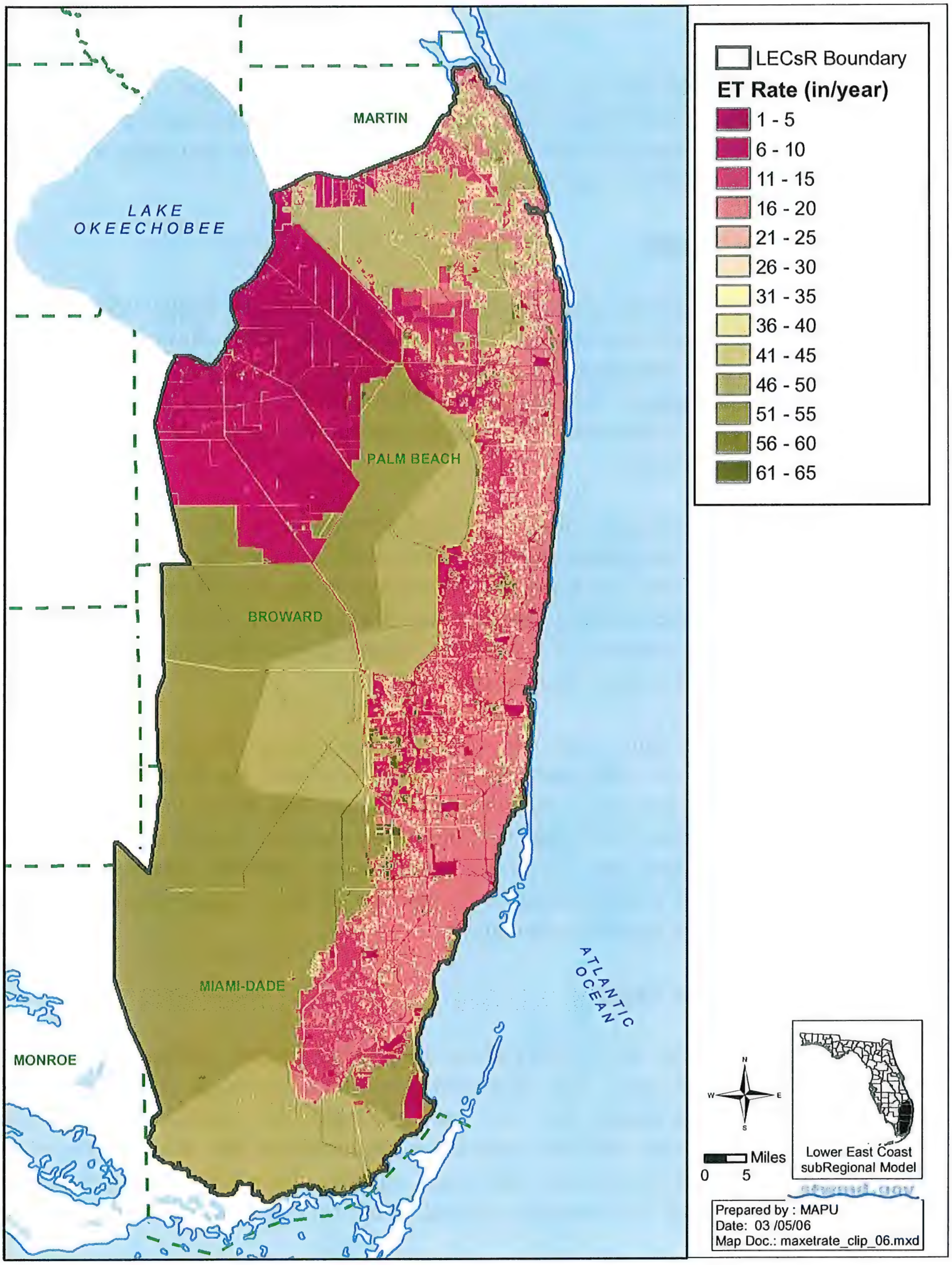


Figure 74. Average Annual Maximum Evapotranspiration Rate (in/year) (1986-2000) Groundwater Use.

Water Use

Data for the Well Package were extracted from the individual water use permits issued by the South Florida Water Management District and actual usage reported to the SFWMD and USGS. The individual permits were divided into two categories: public water supply and non-public water supply.

Public Water Supply

Annual allocations (in million gallons per year) for public water supply demands were obtained from monthly pumpage reports supplied by utility companies. Individual well withdrawals were estimated by creating a wellfield distribution percentage and a monthly seasonal component for each permit. The wellfield distributions were changed three times (i.e., 1986, 1989 and 1992) during the simulation period when there were significant shifts in demands.

The annual allocations vary in the model according to the historical pumping records for that year. If the utility does not have a wellfield cap due to a restriction (e.g. wetland impacts, saltwater intrusion), the percentage of the annual allocation is evenly distributed among the total primary number of wells per permit. Most of the PWS wells in the study area are unrestricted. For example, Permit X contains 2 wells; consequently, 50 percent of the pumpage is assigned to each well.

A monthly seasonal component was developed using historical pumpage from January to December of each year. These values represent the fraction of pumpage distributed throughout the year - monthly seasonality. The fractions add to 1.0. If a permit's annual allocation is 120 mgy and the utility reported that 10 mgy was pumped each month, the fractions are 0.0.83 for each month. Monthly pumpages are then converted to daily values by dividing by the number of days in each month. The daily pumping rate was held constant for the month.

Non-Public Water Supply

Non-public water use classifications include agriculture, industry, golf course, nursery, and recreation areas. The historical (or actual) pumpage was applied when available. When the pumpage data were not available, the modified Blaney-Criddle equation was used to calculate the crop water requirements and then to estimate the irrigation demands based on rainfall, crop type, and irrigation efficiencies. In reality, not all of the water pumped for irrigation is used, some of it is returned to the aquifer as recharge.

CHAPTER 4
Model Calibration

Calibration is the procedure by which input parameters are adjusted within the model until a reasonable representation of the physical system is achieved. Model calibration is considered to be accomplished when the model is capable of simulating a set of field measurements within specified tolerances. The goal of the calibration process is to change input parameters, such as boundary conductance or horizontal hydraulic conductivities, within a predetermined range in an attempt to produce simulated heads and fluxes that match historical values. The predetermined ranges for input values are set by a combination of site specific data (e.g. pumping tests) or typical values (e.g. specific yield of fine sand which typically ranges from 0.05 to 0.3). The calibration period chosen for the LECsR model was January 1986 to September 1999, which has a wide range of hydrologic conditions ranging from very dry to average to very wet hydrologic periods. The September, 1999 time period was chosen as the end of the calibration period due to a significant change in the surface water operations of the overall everglades system which occurred in the fall of 1999. The transient calibration comprises 5000 stress periods. Each stress period is a day and has one time step.

The model was calibrated to only to transient conditions as discussed in Chapter 3. The total number of observation wells used in the calibration is 195 which have continuous recorders on them. Figure 80 shows the location of the observation wells. With the notable exception of the use of monthly demands (which were converted to daily averages) for wellfield withdrawals for utility and agricultural demands, daily stress periods were used for the hydrological inputs including rainfall, evapotranspiration, canal stages, structure flows, and general head boundary conditions (tidal and groundwater levels at the boundaries of the model).

Calibration was achieved primarily by adjusting parameters within pre-specified ranges to better match computed water levels and structure flows with the observed historical record. The model was initially run utilizing the original model design. The more sensitive parameter where then varied to there maximum and minimum values and evaluated for statistically significant trends. Max and min values were selected based on physical meaning. For example, horizonal hydraulic conductivity was not less than zero ft/day and did not exceed 75,000 ft/day (which was the highest value in the Biscayne aquifer from pump test). If any noticeable trends were observed by varying any parameter, regional changes were applied to the model to improve calibration. The model was then ran with the new parameters and compared to the previous "calibrated" model to determine the extent of improvement. If significant improve was observed, the model was permanently modified to include these changes. This process was repeated multiple times by slowly decreasing the minimum and maximum tolerances of the parameters extremes until a satisfactory calibration was achieved. At no time were the minimum and maximum tolerance values exceed during the process. The final results of

the model runs were subsequently evaluated both qualitatively and quantitatively. No automated calibration tools were utilized in the calibration process.

CALIBRATION CRITERIA AND TARGETS

The mean error, the mean absolute error and the root-mean square error are the statistics that are commonly used to evaluate the comparison between simulated and observed heads (Anderson and Woessner 1992). Langevin (2001) suggest that the mean absolute error "may be the most useful statistic because it provides a true measure of the average difference between observed and simulated heads". However, other authors have used either the mean error or root-mean square error as their primary statistical indicator (Anderson and Woessner 1992). In addition, the South Florida Water Management District has historically used statistical criteria of plus or minus 1.0 feet for 75 percent of the simulation period (Restrepo et al. 1992) for the Lower East Coast of Florida. The limitation of this criteria is that it is independent of the variability of well. For this analysis, statistical indicators +/- 1.0, ME, MAE and RMSE will be considered the primary indicators with STD, MIN/MAX and RES as the secondary indicators.

In order to determine if the LECsR Model is simulating hydrologic and hydrogeologic system accurately, a series of calibration targets were developed prior to model execution. A series of seven statistical measures were evaluated to assist in determining the degree of calibration for the model. These statistical measures were applied to the overall model and each individual well.

For the entire model area, the following seven statistical criteria are calculated:

- Residual (RES global) = Average over all 195 observation wells of RES
- Standard deviation (STD global) = Average over all 195 observation wells of STD
- MIN/MAX global = Average over all 195 observation wells of MIN/MAX
- +/- 1.0 global = Average over all 195 observation wells of +/- 1.0
- Mean error (ME global) = Average over all 195 observation wells of ME
- Mean absolute error (MAE global) = Average over all 195 observation wells of MAE
- Root mean square error (RMSE global) = Average over all 195 observation wells of RMSE

For each observation well, the following seven statistical criteria are calculated:

- RES = Percentage of time where the absolute value of the simulated residual minus the standard deviation of the residual is less than 25%

of the difference between the maximum and minimum observed heads for each observation well.

- STD = Percentage of time where the simulated head lies within the range of the observed head for that day plus or minus the observed head's standard deviation for the period of record if the standard deviation is greater than 1.0 feet for each observation well. If it is less than 1.0 feet, than 1.0 feet is utilized. This is a modification of +/- 1.0 (see below) to allow for those wells which may experience extreme fluctuations.
- MIN/MAX = Percentage of time where simulated head lies within the range of the observed heads minimum and maximum value for each observation well.
- +/- 1.0 Foot = Percentage of time where simulated head lies within a plus or minus one foot band of the observed head for each observation well.
- ME = the mean error (ME) is the mean difference between measured and simulated heads for each observation well.
- MAE = the mean absolute error (MAE) is the mean of the absolute value of the differences in measured and simulated heads for each observation well.
- RMSE = the root mean squared error (RMSE) is the average of the squared differences in measured and simulated heads for each observation well.

The seven global model criteria should not be used to ensure a satisfactory calibration in the model. However, they do represent objective numerical criteria which normally are indicative of calibration accuracy. Considering this model is a transient model with 5000 daily stress periods, it is not reasonable to expect that ever criteria can be met 100 percent of the time for those calibration targets which record if the simulated head fell within the predetermined range on a daily basis. Therefore, the calibration targets include a percentage, or an absolute number, depending upon which statistical criteria that is being looked at.

Table 10. Ranges and Targets for statistical calibration criteria.

Statistical criteria	**Proposed range or Target**
Global model criteria	
RES	80 %
STD	80 %
MIN/MAX	80 %
+/- 1.0 Foot	80 %
ME	+/- 0.75
MAE	0.75 ft
RMSE	0.75 ft
Individual observation well criteria	
RES	75 %
STD	75 %
MIN/MAX	75 %
+/- 1.0 Foot	75 %
ME	+/- 1.0
MAE	1.0
RMSE	1.0

The statistical criteria listed in **Table 10** should be regarded as calibration targets, i.e., if the input data, the number of observation wells and the individual observations time series allow it, the calibration should be continued until the criteria are met. In general the model should describe the average level and the dynamics of the groundwater table fairly accurately. The criteria may serve to check if the deviations between simulation and observation have been sufficiently reduced.

'Soft' calibration references

Apart from field measurements, the model may be evaluated from a more general view. The 'soft' calibration references could include the general shape of the potentiometric surface, regional flow paths, aerial photography and ground truthing when evaluating inundated areas, and wetland community types and the environments that they thrive in.

The model results are evaluated from the general knowledge and understanding of the model area. As no 'hard' data in terms of measurements exist, the comparison between simulations and the field conditions is qualitative. An example is where a known wetland community exists which has a distinct hydroperiod which may indicate

that water is above ground for 3 months out of the year. An average year would be evaluated to see if the simulated water levels are reasonable for the type of wetland community. Another example for soft calibration includes analyzing the typical regional flow pattern in the calibration runs.

Calibration Process

The calibration process was conducted in a uniform manner. First the model was originally run with the conceptual model and evaluated utilizing the calibration criteria established. The initial model run was reasonably calibrated considering the model was a partial combination of pre-existing calibrated models. However, these previous models did not have calibration periods remotely close to the 5000 stress periods utilized in this model. Therefore, additional calibration was necessary to achieve the desired goals. The first step in the calibration process was to vary all model parameters to there minimum and maximum values. Each of these runs were then compared to the original conceptual model for a determination of any improvements or degradation to the model calibration. For these first set of model simulations, every parameter was evaluated to see if the model was sensitive to that parameter. If the model was sensitive to that particular parameter in either a positive or negative way, it was retained for the calibration process. **Table 11** shows the main parameters utilized in the calibration process and the tolerance levels imposed on each parameter.

Table 11. Tolerance levels utilized during calibration process

Model Parameter	Minimum Value	Maximum Value
General Head Boundary Conductance (ft2/day)	Original divided by 100	Original Multiplied by 100
Canal Hydraulic Conductivity of the Sediments	0.1 ft/day	100 ft/day
Canal sediment thickness	0.1	5
Specific Yield for the wetlands and underlying	0.2	0.8

muck layer Hydraulic Conductivity of Layer one in wetland areas	25 ft/day	100,000 ft/day

General Head Boundary Conductance

The general head boundary was modified in portions of Palm Beach and Martin Counties. The conductance values were decreased by a factor of 100 along Lake Worth Lagoon and Jupiter Inlet. Noticeable improvements were observed in wells PB-565, M-1024, PB-1642, PB-809 and PB-1639. The reduction in the conductance value is at the extreme end of the range suggesting. The reduction in conductance values suggests that boundary conditions may influence water levels in this area of the model. Further reductions in conductance values in this area showed no noticeable improvement and worsen the calibration in several places. A total of six iterations were made to achieve the final general head conductance boundary. With the exception of central and northern Palm Beach and southern Martin County along the eastern boarder of the model, no changes were made to the general head conductance values elsewhere in the model.

River and Drain Conductance

Modifications to the river and drain conductance values, and to there assignment as rivers or drains, was the most intensive calibration effort undertaken for a number of reasons. In the conceptual model run, it became apparent that large numbers of canals were missing from the GIS coverages, and that data in the attribute fields for the existing canals was either absent or not correct. In addition, some of the existing canals were either in the wrong location or had an incorrect structure assigned to them. Initially, existing GIS coverages were obtained to fill in the missing canals. Then from an iterative process, each area of the model was evaluated further to investigate if additional canals were missing or mislabeled. This took numerous iterations to complete. Canal conductance values were modified by changing the thickness of the sediments in the canal. Initially, the sediment thickness was set to 1. Sediment thicknesses were then allow to vary between 0.1 feet and 5 feet which is within the range of sediment thickness found in the study area because some canals have near vertical slopes due to the rock they are cut into. The hydraulic conductivity of the sediments was initially set to 1 but was allowed to vary between 0.1 and 100 which still may be low considering the extremely porous nature of the Miami Limestone and Fort Thompson Formation which the canals cut into in Miami-Dade, Broward and southern Palm Beach County. In general, canal conductance tends to increase from north to south primarily due to Miami Limestone and Fort Thompson Formations which are outcropping in the southern portion of the model.

Specific Yield of the Wetlands Muck Layer

The specific yield of the wetlands muck layer was originally set to 0.6. This value was chosen to try and simulate those areas where both wetlands and uplands were present in a single model cell. The reason for doing this was that the topo tended to favor the upland values and the isolated wetlands which are lower would not be accounted for. During the calibration process, the specific yield of the muck was allowed to vary between 0.2 and 0.8. The simulations determined that the 0.6 was too high for the specific yield of the muck and was reset to a more realistic value of 0.3 for the majority of the wetland areas in the model domain.

Root Zone Extinction Depth and ET Surface Elevations

The root zone extinction depth and the ET Surface elevation controls, in part, the amount of evapotranspiration that is removed from the saturated zone of the water table. The process for creating the water table ET and water table recharge attempts to account for water removed from the saturated zone. Therefore, in areas that are heavily irrigated, ET from the saturated zone in low because the potential ET is removed from the unsaturated zone because it is constantly irrigated.

The ET function in the governing equation is a linear function and is dependent upon the depth of the root zone and the ET surface elevation relevant to the elevation of the water table. If the root zone depth is to shallow and the ET surface to high compared to the calculated head at that location, then little or no ET would be removed from the model. Conversely, larger amounts of ET would be removed if the ET land surface was low and the root zone deep when compared to the head calculated at that cell.

Root zone depths were decreased in the Corbett Wildlife Management Area, the Tequesta area, and southeastern Miami-Dade County. The ET surface was also lowered in extreme southwestern Corbett Wildlife Management Area and the West Palm Beach Water Catchment Area. Known issues regarding the topography in northern Palm Beach County potentially being to high allowed some manipulation of the topography in these regions. The ET surface was slightly increased in Everglades National Park along the marl uplands to better simulate these features.

Wetland Hydraulic Conductivity and Overland Flow Elevations

The wetland hydraulic conductivity of the muck was originally set to values equal to layer one, as calculated from the hydrogeology of the units in layer one. These values generally ranged from approximately 25 ft/day to over 50,000 ft/day. The calibration process found that a value of 5,000 ft/day was generally sufficient to calibrate the wetland gages in most of the wetland systems. The one main exception to this was Shark River Slough.

Shark River Slough is a deep slough system located in Everglades National Park. It is a broad southwesterly trending arc originating at the upper northeastern portion of

the park and terminating at Florida Bay in the southwestern portions of the park. It is a continuous deep wetland system interspersed with tree islands and is within a slight trough located within the underlying limestone. The system is managed by a series of pump stations and numerous culverts located along Tamiami Trail. Due to the low topographic relief in the area, the hydraulic conductivity of the muck and the overland flow elevations had to be modified significantly to achieve calibration. The hydraulic conductivity of layer one was increased to 500,000 ft/day and the topography lowered by a foot to help water move through the slough (or preferential flow path).

Urban Recharge

The final main changes made to the model during the calibration process was a modification to the et-recharge preprocessing program. This program calculates recharge to the water table dependent upon the amount of water retained in the unsaturated zone with some of the main input parameters including soil type, landuse, and crop type. The model originally utilized and standard curve number approach for estimating runoff for the various land uses in the study area. A slight improvement was noted in the majority of the urban areas when the curve number runoff estimates was not utilized. There are two apparent reasons for not utilizing runoff estimates in the model. The extreme amount of secondary canal systems, coupled with the high hydraulic conductivity of the Biscayne aquifer, rapidly removes water from the model, which, in effect is simulating the overland flow component. Second, south Florida has undergone tremendous development of the last 20 to 30 years. Developments that have recently been constructed are required to have onsite lake systems and surface water treatment facility to retain storm water onsite. So the runoff from these newer developments is limited to within the development itself and generally does not discharge to the primary canal systems except under heavy rainfall conditions. Even when they do discharge to the primary canal systems, there is a lag of hours to days where the water is retained on site prior to discharge. Considering the model is operating on a daily stress period and time step, this allows the river and drain package sufficient time to remove the excess runoff.

Global Model Calibration

During the calibration process, observations wells with continuous data recorders were analyzed. The location of the observation wells are shown in **Figure 78**. **Table 12** present the statistical results of the over all model calibration.

Table 12. Calibration Results for the Entire Model Domain (195 observation wells)

Statistical criteria	Proposed Target	Simulated Range
RES Global	85%	100 %
STD Global	85 %	80 %
MIN/M	85 %	99 %

AX Global		
+/- 1.0 Global	85 %	87 %
ME Global	+/- 0.75 ft	0.00 ft
MAE Global	0.75 ft	0.55 ft
RMSE Global	0.75 ft	0.70 ft

The global calibration results indicate that 6 out of the 7 criteria were met. The global model calibration was not within 1 standard deviation more than 85 percent of the time; however, the target was missed by only 5 percent. Based on these results, the model is calibrated under the global criteria. It should be noted that this result in upon itself is not indicative of a calibrated model but does provide a reasonable starting point in evaluating the effectiveness of the calibration.

Figure 75 shows a histogram of the distribution of the mean error for each of the observation wells. For the entire model the mean error distribution appears to be symmetrical distribution with a slight bias to the positive side. This indicates that the overall model may be slightly over-predicting heads. The original calibration criteria target for was plus or minus 1.0 feet or less. The graph indicates that approximately 95 percent of the wells meet this condition.

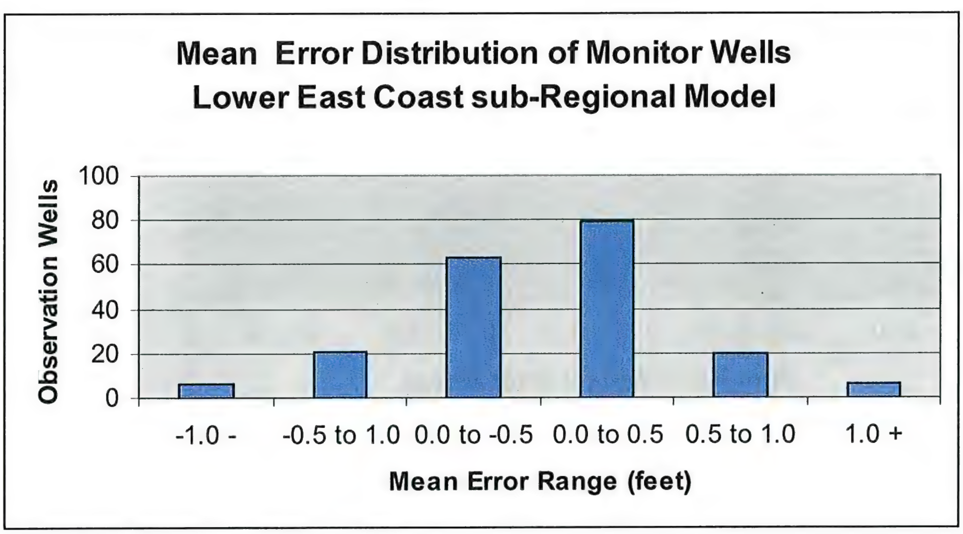


Figure 75. Mean Error Histogram for Model Calibration Period

The histogram for the Mean Absolute Error is presented in **Figure 76**. It is not expected that the histogram should be normally distributed since the mean absolute error indicates no negative values with the theoretical goal of reaching zero for all values. The

graph suggests that over 90 percent of the wells have achieved the calibration goal of 1.0 foot or less.

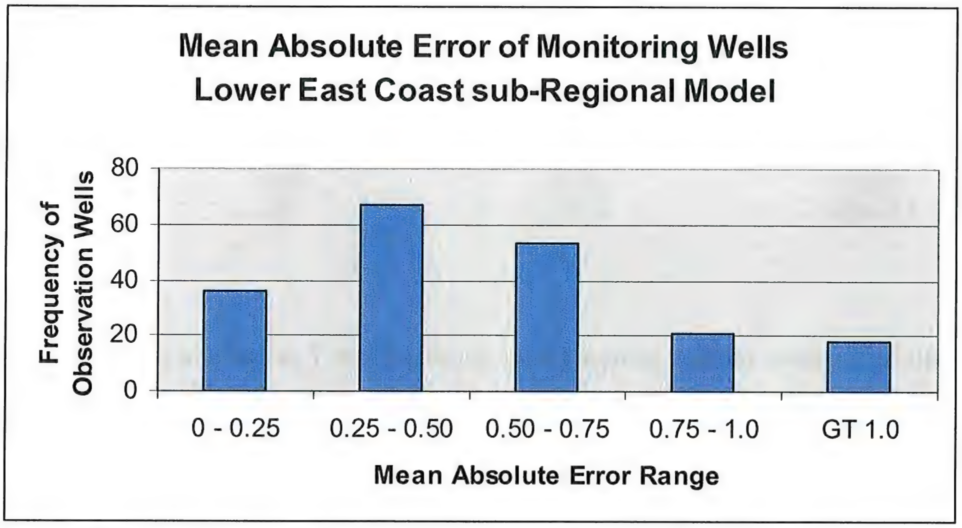


Figure 76. Mean Absolute Error Histogram for Model Calibration Period

The histogram for the Root Mean Square Error is presented in **Figure 77**. Similar to the Mean Absolute Error, it is not expected that the histogram should be normally distributed since the absolute indicates no negative values with the theoretical goal of reaching zero for all values. A slightly lower number of wells reach the calibration criteria of 1.0 foot with approximately 85 percent of the wells below the 1.0 foot target.

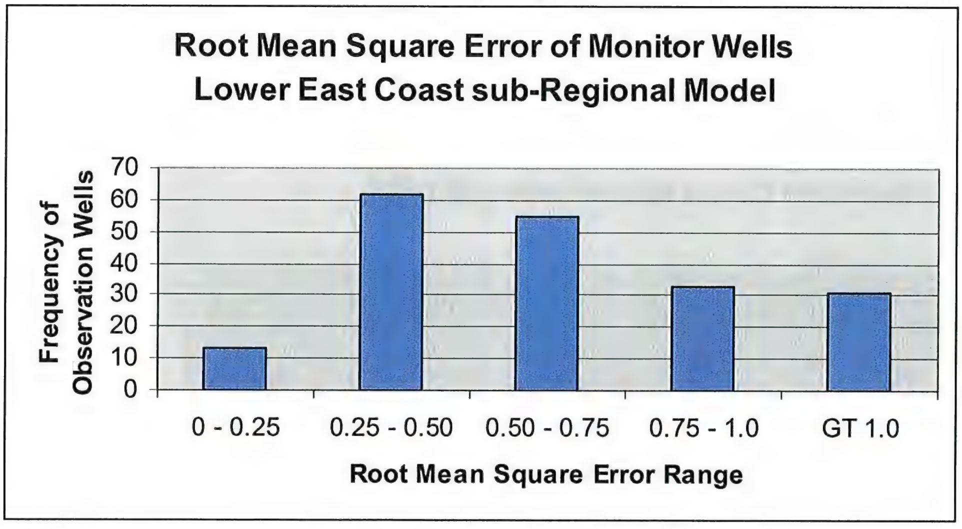


Figure 77. Root Mean Square Error Histogram for Model Calibration Period

The final primary calibration statistic is plus or minus 1.0 foot which is that the simulated data should be within a band of plus or minus one foot for a minimum of 75 percent of the time. The calibration results indicate that approximately 78 percent of the wells meet or exceed this condition.

Of the three secondary calibration statistics the objective was to achieve or exceed the desired result a minimum of 75 percent of the time. For RES, 99 percent of the wells achieve or exceed this condition. For the Min/Max and STD statistical criteria, they meet or exceed there condition 81 and 99 percent respectively. It should be noted that the S2 secondary calibration statistic reports slightly better calibration results than the S4 calibration statistic. The S4 calibration statistic is a plus or minus 1.0 foot band where the S2 calibration statistic keeps the plus or minus 1.0 foot band but allows the band to expand for those observation wells where the standard deviation exceeds 1.0 feet. The observation wells where this occurs are areas where fluctuation of the water table is more extreme.

Individual Well Calibration

The same observations wells with continuous data recorders were analyzed for the individual well calibration. **Table 13** presents the statistical results of the individual well calibration. **Figures 78** through **81** show the location of the monitoring stations.

Table 13. Statistics for Calibration Period.

Well	Residual	Std Dev	Min/Max	+/-1 Foot	ME	MAE	RMS
1-7	100	71.21	99.24	90.55	-0.25	0.44	0.57
1-9	100	70.79	98.58	93.94	-0.4	0.45	0.56
2A-17	100	73.8	100	78.02	-0.04	0.66	0.78
2B-Y	100	93.71	96.75	70.97	-0.31	0.79	1.13
ANGEL	99.96	94.21	100	91.34	0.12	0.49	0.79
EVER1	100	67.19	99.98	99.68	-0.19	0.26	0.33
EVER2A	100	89.24	99.89	99.91	-0.23	0.26	0.31
EVER2B	100	91.49	99.9	99.98	-0.21	0.24	0.29
EVER3	99.9	93.17	99.92	99.83	-0.16	0.2	0.25
EVER4	99.84	90.14	99.54	99.6	-0.2	0.25	0.31
F239	99.9	72.24	100	76.11	-0.39	0.66	0.84
F291	99.32	79.17	100	96.27	-0.26	0.5	0.6
F319	99.36	87.36	99.61	98.34	0.11	0.2	0.33
F358	99.16	80.92	99.88	92.52	0.48	0.49	0.64
F45	98.83	81.11	100	91.15	0.37	0.42	0.61
FROGP	99.56	96.54	99.92	99.06	0.07	0.16	0.25
G1074B	100	25.63	100	9.27	-4.77	5.1	5.71

Well	Residual	Std Dev	Min/Max	+/-1 Foot	ME	MAE	RMS
G1166	99.08	85.46	99.49	98.1	0.16	0.2	0.32
G1183	99.21	83.92	100	96.91	0.02	0.27	0.4
G1213	98.34	82.91	100	81.84	0.27	0.63	0.81
G1220	99.49	92.61	100	97.37	0.02	0.32	0.42
G1221	98.74	91.38	100	96.45	0.03	0.31	0.52
G1223	98.22	78.86	99.46	91.62	0.4	0.46	0.61
G1224	99.8	89.63	100	98.4	-0.27	0.4	0.47
G1225	98.18	76.55	100	81.97	0.53	0.56	0.74
G1226	99.79	93.83	100	97.36	-0.03	0.31	0.46
G1260	97.74	59.94	100	29.4	1.48	1.51	1.74
G1315	99.88	99.17	99.96	98.36	-0.02	0.11	0.25
G1316	99.4	73.24	100	93.63	-0.02	0.43	0.55
G1362	99.27	92.24	100	95.82	0.14	0.28	0.44
G1363	99.24	94.22	100	95.76	0.01	0.31	0.48
G1473	99.22	79.7	100	95.9	-0.26	0.5	0.61
G1486	99.68	94.66	100	98.36	0.1	0.17	0.3
G1487	99.88	96.64	99.8	98.35	0.14	0.29	0.38
G1488	99.82	98.8	98.02	99.37	-0.03	0.27	0.35
G1636	99.86	77.69	100	98.19	-0.22	0.36	0.44
G1637	99.88	83.16	100	98.56	0.29	0.37	0.45
G2031	99.36	78.76	100	95.87	0.03	0.39	0.5
G2032	99.05	73.6	97.65	94.32	0.13	0.4	0.52
G2033	98.77	70.92	99.92	89.56	-0.12	0.46	0.62
G2034	99.36	76.42	99.94	91.3	0.06	0.45	0.6
G2035	99.46	93.76	100	97.04	-0.07	0.33	0.45
G2147	100	63.72	100	48.85	-0.88	1.16	1.44
G2395	100	67.35	100	35.84	-0.66	1.67	2.08
G2739	100	63.56	99.54	81.1	-0.42	0.57	0.78
G2852	100	69.66	100	54.6	-0.04	1.11	1.4
G2866	100	10.66	100	1.99	3.26	3.27	3.45
G3074	100	73.88	100	66.78	-0.87	1.16	1.7
G3253	100	79.03	100	13.7	-0.72	2.25	2.5
G3259A	100	98.82	100	47.94	0	1.04	1.17
G3264A	99.86	98.36	99.98	98.02	0.11	0.3	0.41
G3272	100	87.02	98.46	98.81	0.13	0.37	0.47
G3273	99.76	90.54	97.46	87.96	0.07	0.52	0.66
G3327	99.6	81.81	100	97.93	0.02	0.28	0.39
G3328	99.72	88.42	100	99.28	-0.02	0.18	0.25
G3329	98.98	72.2	99.69	92.62	0.4	0.41	0.55
G3353	99.98	78.7	98.59	97.79	-0.25	0.3	0.39
G3355	98.26	80.65	100	93.02	0.33	0.39	0.55
G3356	95.4	71.1	99.86	93.01	0.35	0.41	0.52
G3437	100	86.83	100	84.97	0.38	0.52	0.68
G3439	100	91.25	99.9	93.55	-0.37	0.46	0.57
G3465	100	71.39	100	84.27	0.05	0.61	0.73
G3466	100	67.98	100	64.21	-0.06	0.85	1.01
G3467	100	74.49	100	97.83	-0.15	0.37	0.48

Well	Residual	Std Dev	Min/Max	+/-1 Foot	ME	MAE	RMS
G3473	100	91.59	100	96.62	0.07	0.27	0.41
G3549	100	45.01	100	99.37	0.24	0.27	0.32
G3550	100	85.38	99.69	99.63	0.05	0.16	0.22
G3551	100	93.56	100	99.52	-0.13	0.22	0.33
G3552	100	86.96	99.9	96.26	0.26	0.35	0.47
G3553	100	57.03	100	81.64	0.66	0.68	0.78
G3554	100	34.05	100	59.97	0.93	0.94	1.04
G3555	100	75.38	100	89.5	0.47	0.5	0.65
G3556	100	61.88	100	85.1	0.6	0.63	0.73
G3557	100	96.3	100	99.64	-0.03	0.23	0.32
G3558	100	93.6	100	97.61	-0.12	0.26	0.37
G3559	100	96.34	99.59	99.69	0.09	0.14	0.23
G3560	100	79.97	99.89	92.96	0.35	0.41	0.56
G3561	100	44.92	100	74.99	0.76	0.77	0.92
G3563	100	80.69	100	94.64	0.34	0.36	0.54
G3564	100	89.36	100	95.07	0.09	0.33	0.48
G3565	100	64.56	100	91.46	0.49	0.5	0.64
G3566	100	62.68	100	78.29	0.61	0.64	0.89
G3567	100	39.14	100	95.86	0.6	0.61	0.67
G3568	100	85.43	100	97.03	-0.2	0.38	0.48
G3570	100	74.33	100	76.47	0.66	0.68	0.99
G3572	100	88.08	100	96.77	0.1	0.26	0.43
G3576	100	76.49	100	99.7	0.3	0.31	0.39
G3619	100	92.63	100	99.28	0.15	0.2	0.26
G3620	100	89.98	100	99.34	0.05	0.17	0.25
G3621	100	87.24	100	99.84	-0.17	0.23	0.3
G3622	100	92.6	100	98	-0.12	0.35	0.45
G3626	100	20.87	100	79.39	-0.67	0.73	0.8
G3627	100	86.67	100	98.28	-0.2	0.3	0.4
G3628	100	93.07	100	97.32	0.04	0.23	0.37
G3676	100	90.91	94.55	99.27	-0.33	0.41	0.55
G3A	100	49.74	100	44.98	-1.22	1.32	1.64
G551	99.89	71.89	100	67.66	-0.31	0.84	1.08
G553	99.07	79.39	99.07	90.78	0.51	0.52	0.62
G561	99.41	86	100	94.39	0.16	0.35	0.48
G580A	99.26	89.2	99.78	96.96	0.21	0.24	0.42
G614	99.36	93.64	99.98	96.21	-0.11	0.36	0.5
G617	96.91	72.46	98.12	90.92	0.35	0.41	0.59
G620	100	81.09	96.74	86.5	-0.21	0.53	0.66
G757A	99.43	94.89	100	97.22	0.1	0.24	0.4
G789	99.72	73.83	100	97.17	-0.45	0.52	0.58
G852	98.73	85.53	100	95.86	0.05	0.32	0.47
G853	100	66.37	100	40.5	-1.09	1.7	2.13
G855	99.2	89.71	100	94.15	0.28	0.37	0.52
G860	99.88	91.72	99.94	98.74	0.13	0.19	0.3
G864	98.76	88.2	100	92.46	0.31	0.38	0.64
G864A	98.95	90.61	100	94.03	0.18	0.33	0.57

Well	Residual	Std Dev	Min/Max	+/-1 Foot	ME	MAE	RMS
G968	100	94.72	100	94.57	0.32	0.41	0.51
G970	99.72	88.2	100	99.07	0.03	0.22	0.31
G973	99.61	92.45	100	98.86	0.1	0.21	0.31
G975	99.54	96.84	99.18	98.06	0.02	0.35	0.46
G976	100	97.11	100	81.23	0.24	0.63	0.74
HUMBLE	99.63	97.31	100	98.56	-0.07	0.26	0.35
JD12	100	85.99	100	96.01	0.29	0.38	0.7
JD26	100	79.9	90.01	89.53	-0.43	0.46	0.72
JD6	100	5.82	23.27	47.87	-1.17	1.17	1.28
JDMW1	100	83.16	99.68	57.69	-0.76	0.95	1.17
JDMW3	100	87.62	99.46	54.9	-0.9	1.11	1.4
KROME	100	81.04	100	94.19	0.53	0.55	0.63
L30L67A	100	98.48	99.8	99.8	0.04	0.14	0.32
L67A	100	99.29	100	99.59	0.39	0.43	0.57
M1024	100	32.76	99.12	30.96	-1.55	1.57	1.79
M1234	100	65.69	100	69.37	0.42	0.8	1.09
NESRS1	99.42	80.37	91.66	93.03	-0.16	0.38	0.51
NESRS2	99.69	89.38	95.32	99.34	-0.03	0.28	0.36
NESRS4	99.24	77.41	94	93.28	0.07	0.38	0.51
NESRS5	93.07	65.2	79.55	87.92	0.24	0.46	0.62
NP112	100	83.6	100	88.18	0.52	0.62	0.7
NP127	99.93	90.99	99.67	96.41	-0.09	0.3	0.41
NP146	100	86.39	99.68	99.73	-0.1	0.21	0.28
NP158	99.93	96.88	100	99.11	-0.04	0.32	0.39
NP-201	100	94.86	97.49	96.48	0.03	0.38	0.48
NP-202	99.54	89.46	97.39	93.78	0.15	0.44	0.55
NP-203	98.51	84.11	95.68	92.15	0.07	0.46	0.58
NP-205	100	82.84	96.38	81.1	-0.02	0.59	0.8
NP-206	99.23	81.18	96.04	72.37	0.18	0.78	0.95
NP311	99.98	91.22	99.76	80.22	0.26	0.63	0.75
NP-33	98.43	77.24	96.78	86.35	0.28	0.48	0.65
NP-35	99.96	99.84	99.94	99.96	0	0.08	0.12
NP-36	99.18	66.49	97.7	86.17	0.42	0.56	0.68
NP-38	100	96.69	100	99.36	0.01	0.19	0.26
NP-44	100	80.24	99.58	58.59	0.03	0.93	1.1
NP-46	99.35	82.75	100	96.31	0.08	0.35	0.45
NP-62	100	91.45	99.16	91.6	0.02	0.48	0.66
NP-67	99.9	89.72	99.84	95.96	-0.01	0.34	0.45
NPA13	100	79.42	100	90.65	0.23	0.57	0.68
NPCHP	99.93	83.34	100	96.51	-0.02	0.32	0.43
NPCR2	100	91.17	100	94.27	0.29	0.55	0.63
NPCR3	100	78.26	100	86.29	0.35	0.62	0.71
NPCY2	100	78.4	100	94.38	0.26	0.46	0.56
NPCY3	100	62.17	100	87.69	0.42	0.6	0.68
NPDO1	100	84.78	99.89	83.69	-0.16	0.6	0.76
NPDO2	100	71.7	100	77.59	0.4	0.7	0.82
NPEP1	100	99.02	98.9	100	-0.06	0.11	0.14

Well	Residual	Std Dev	Min/Max	+/-1 Foot	ME	MAE	RMS
NPEPS	100	67.91	99.03	99.89	-0.19	0.28	0.34
NPEV6	100	89.3	99.69	99.73	0.13	0.19	0.25
NPEV7	100	73.8	99.92	99.47	0.22	0.27	0.33
NPEV8	100	64.55	99.23	99.58	-0.36	0.37	0.43
NPN10	100	87.99	99.88	94.66	0.36	0.49	0.59
NPN14	100	79.41	99.77	69	0.32	0.71	0.87
NPNTS1	99.98	95.51	100	98.25	0.2	0.28	0.46
NPP37	99.94	88.83	99.84	94.45	-0.13	0.31	0.47
NPROB	100	92.93	100	96.64	-0.19	0.4	0.51
NP-TSB	100	95.71	99.92	93.61	0.15	0.48	0.57
NPTSH	100	87.46	99.4	99.35	0.13	0.27	0.33
PB1491	100	49.02	100	18.41	-2.58	2.9	3.52
PB1639	100	75.91	100	54.3	0.05	1.06	1.31
PB1642	100	82.97	99.95	75.99	-0.04	0.73	1
PB1661	100	83.27	100	92.91	0.15	0.43	0.65
PB1662	100	77.98	100	87.66	-0.29	0.55	0.82
PB1680	100	81.67	100	87.85	0.3	0.51	0.67
PB1684	100	60	100	92.32	0.46	0.49	0.66
PB445	99.73	58.17	100	95.34	0.12	0.45	0.56
PB561	100	77.01	99.98	59.9	-0.35	1.01	1.3
PB565	98.88	72.76	86.68	51.38	0.98	1.12	1.47
PB683	99.73	78.47	98.76	77.54	-0.09	0.67	0.83
PB685	100	97.77	100	95.24	-0.03	0.32	0.62
PB689	100	93.97	100	96.09	-0.09	0.39	0.82
PB732	98.48	77.88	100	80.96	0.31	0.62	0.82
PB809	99.9	40.9	100	54.92	-0.83	0.95	1.08
PB831	99.77	77.58	99.71	79.36	0.05	0.61	0.77
S18	99.55	89.25	100	98.41	-0.02	0.2	0.31
S182	99.38	87.59	100	96.93	0.15	0.24	0.39
S19	99.8	68.88	100	74.66	0.06	0.71	0.84
S196A	99.58	95.74	100	97.47	0.07	0.24	0.38
S329	100	91.08	100	78.58	0.28	0.66	0.78
S68	99.92	70.98	100	51.65	-0.27	1.21	1.46
SWEV5A	99.94	74.15	99.43	95.39	-0.34	0.38	0.47
SYLVA	98.11	75.39	99.06	82.55	0.59	0.6	0.86
WCA363	100	88.82	100	88.08	-0.38	0.54	0.7
WPBCA	100	92	100	93.11	0.04	0.44	0.9

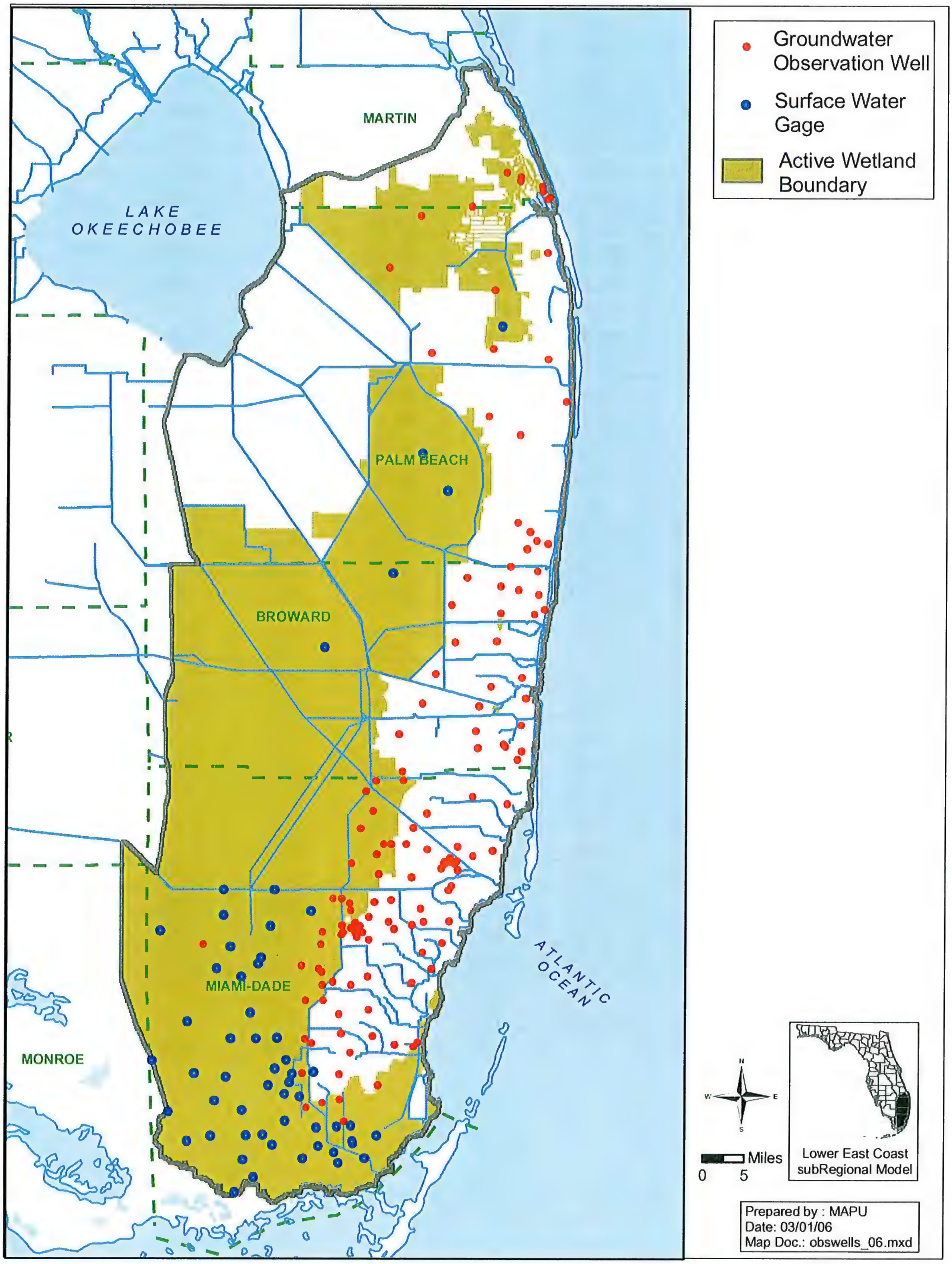


Figure 78. Location of the Observation Network Showing Groundwater Observation Wells and Surface Water Gages.

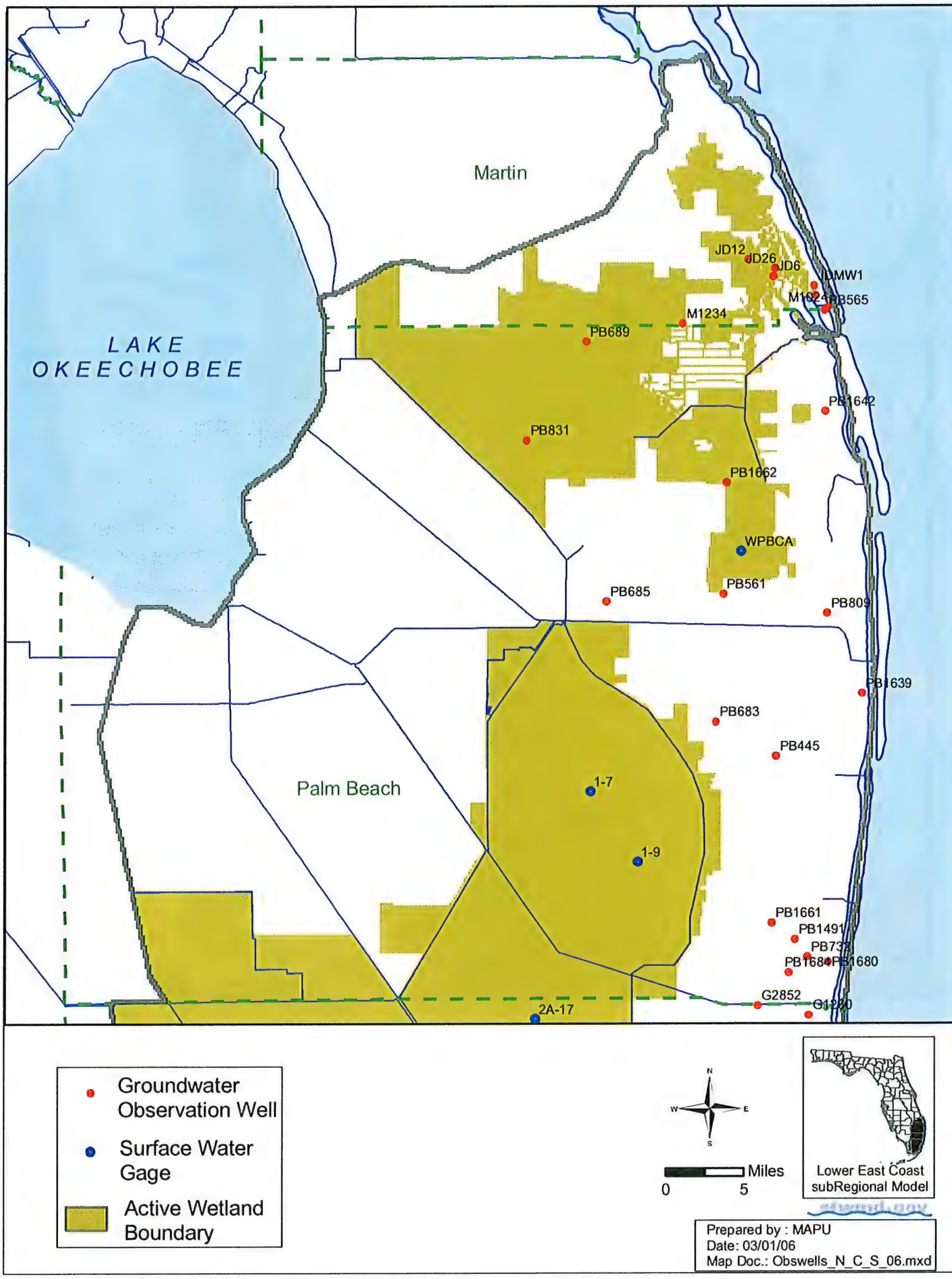


Figure 79. Location of the Observation Network in the Northern Model Area.

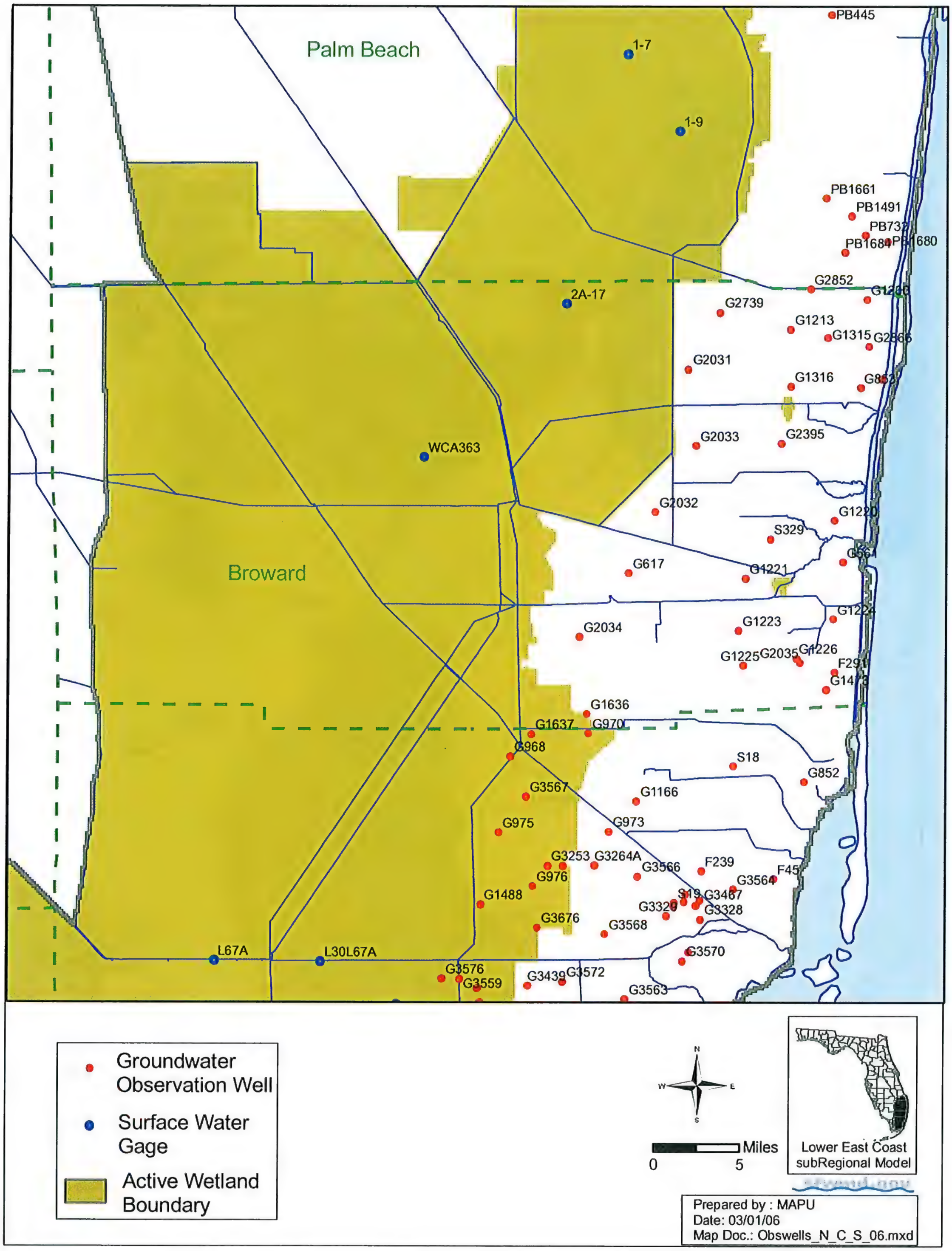


Figure 80. Location of the Observation Network in the Central Model Area.

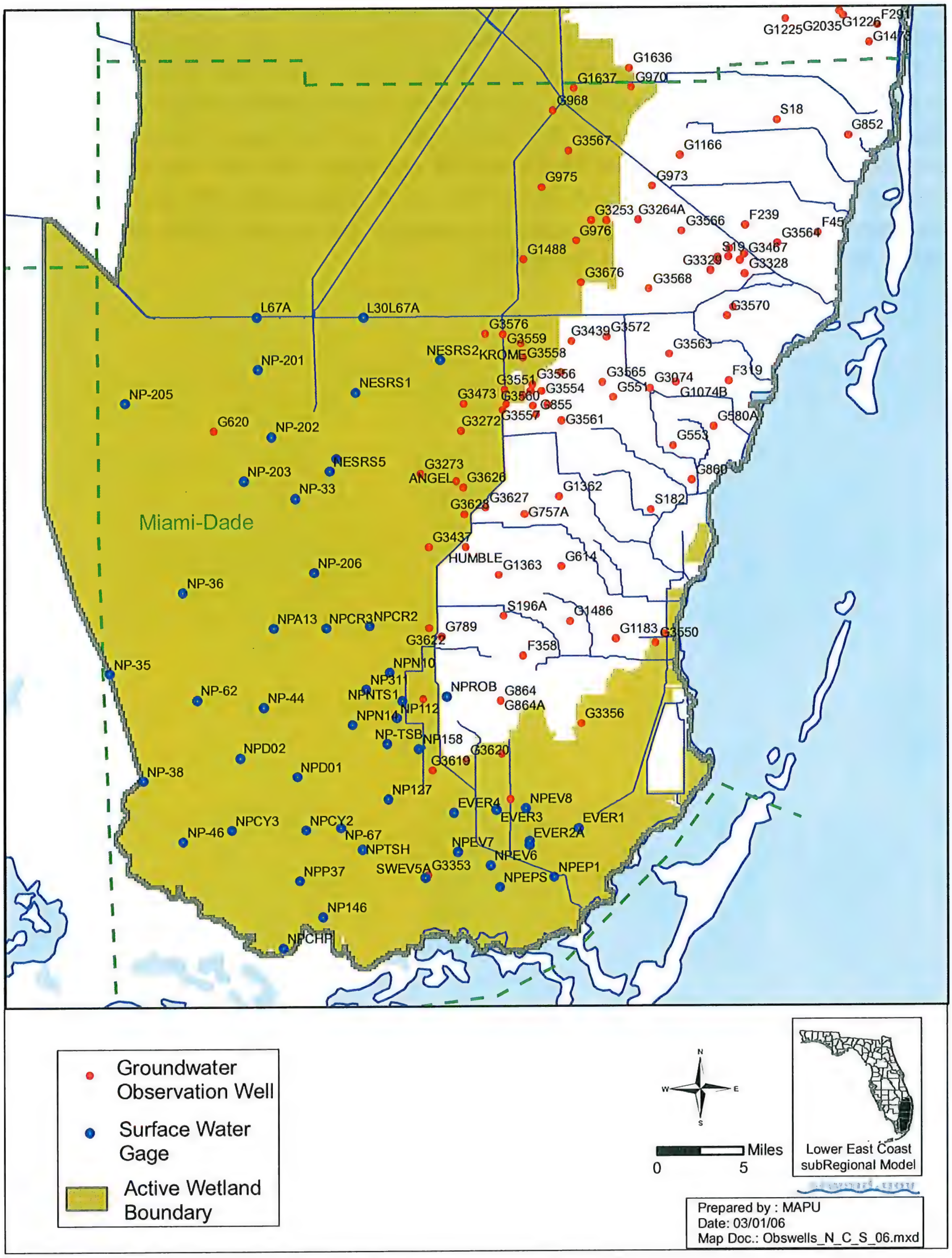


Figure 81. Location of the Observation Network in the Southern Model Area.

In order to determine if any localized trends exist in the calibration results, the mean error was analyzed aerially across the model domain. The mean error was chosen because it would provide insight into localized areas where the model may be over-predicting or under-predicting heads. The location of the monitor wells and surface water gages used in the comparison of the mean error, and the mean error calculations are presented in **Figure 82**. **Figure 83, Figure 84** and **Figure 85** show the water levels for .average (1992), wet (1995) and dry (1989) years **Figures 86, 87 and 88** show the number of days when ponding occurs for average (1992), wet (1995) and dry (1989) years, in the southern portion of the model.

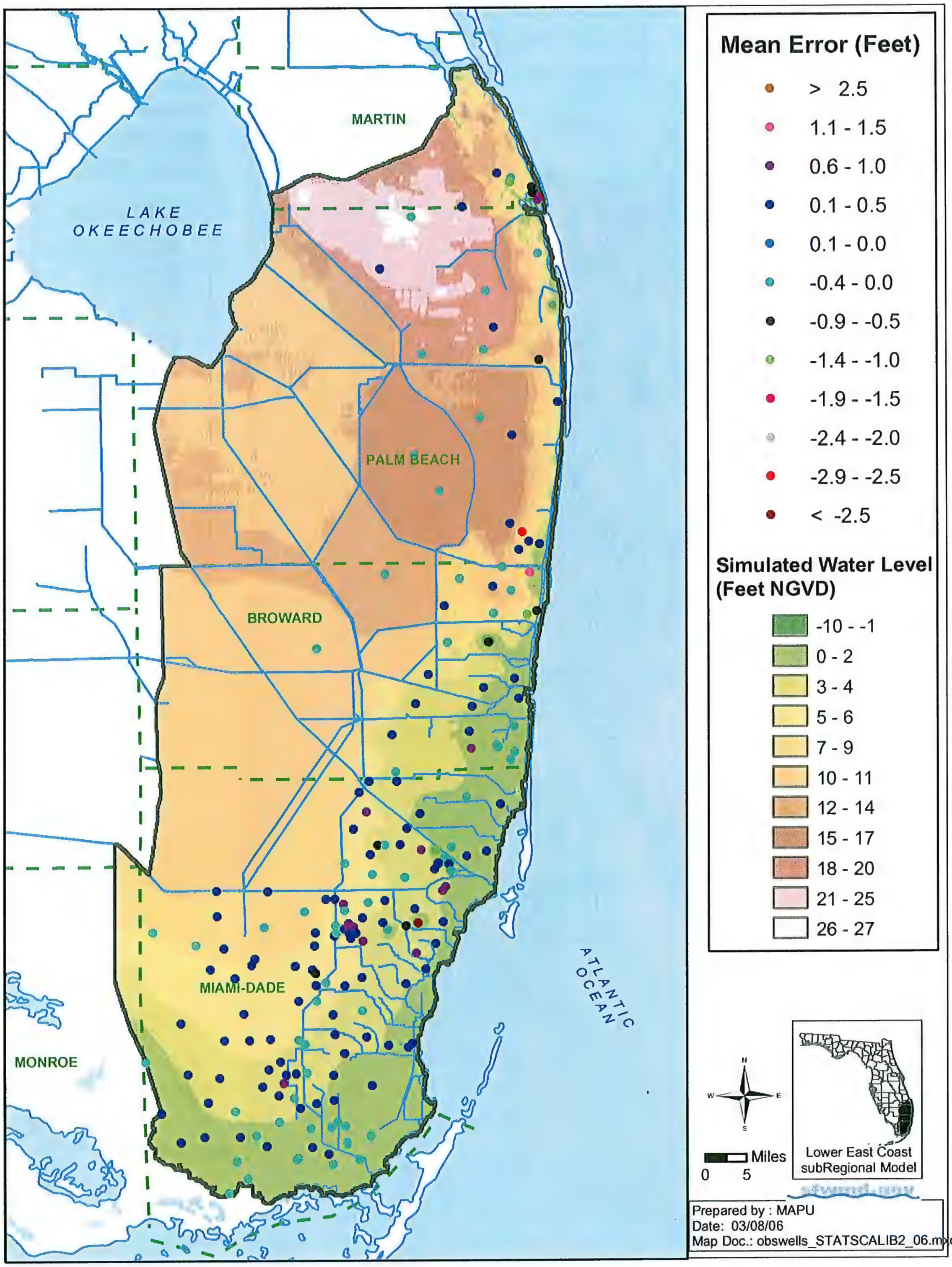


Figure 82. Mean Errors at Observation Sites for Average Daily Water Levels During Model Calibration Run.

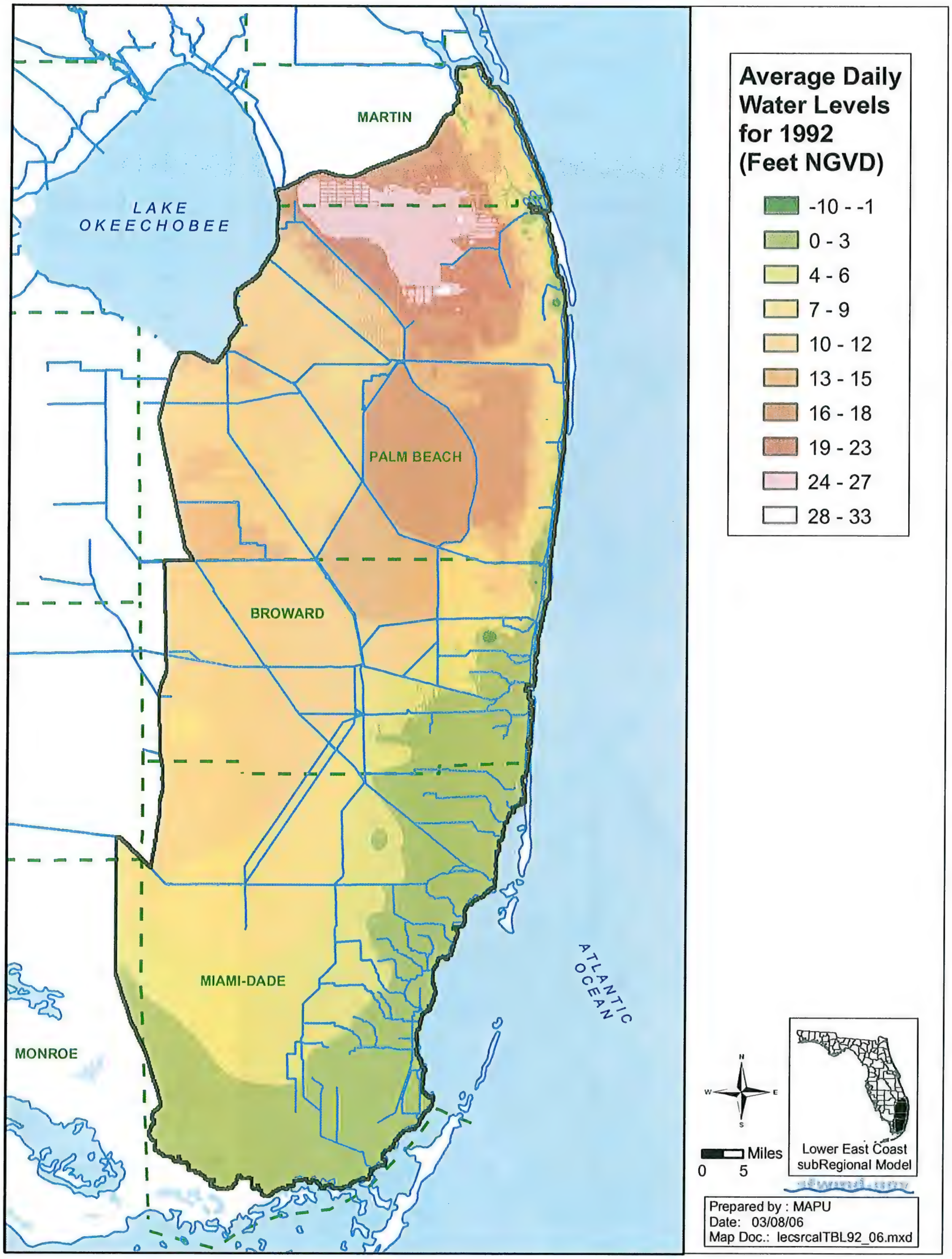


Figure 83. Average (1992) water levels(average daily water levels)

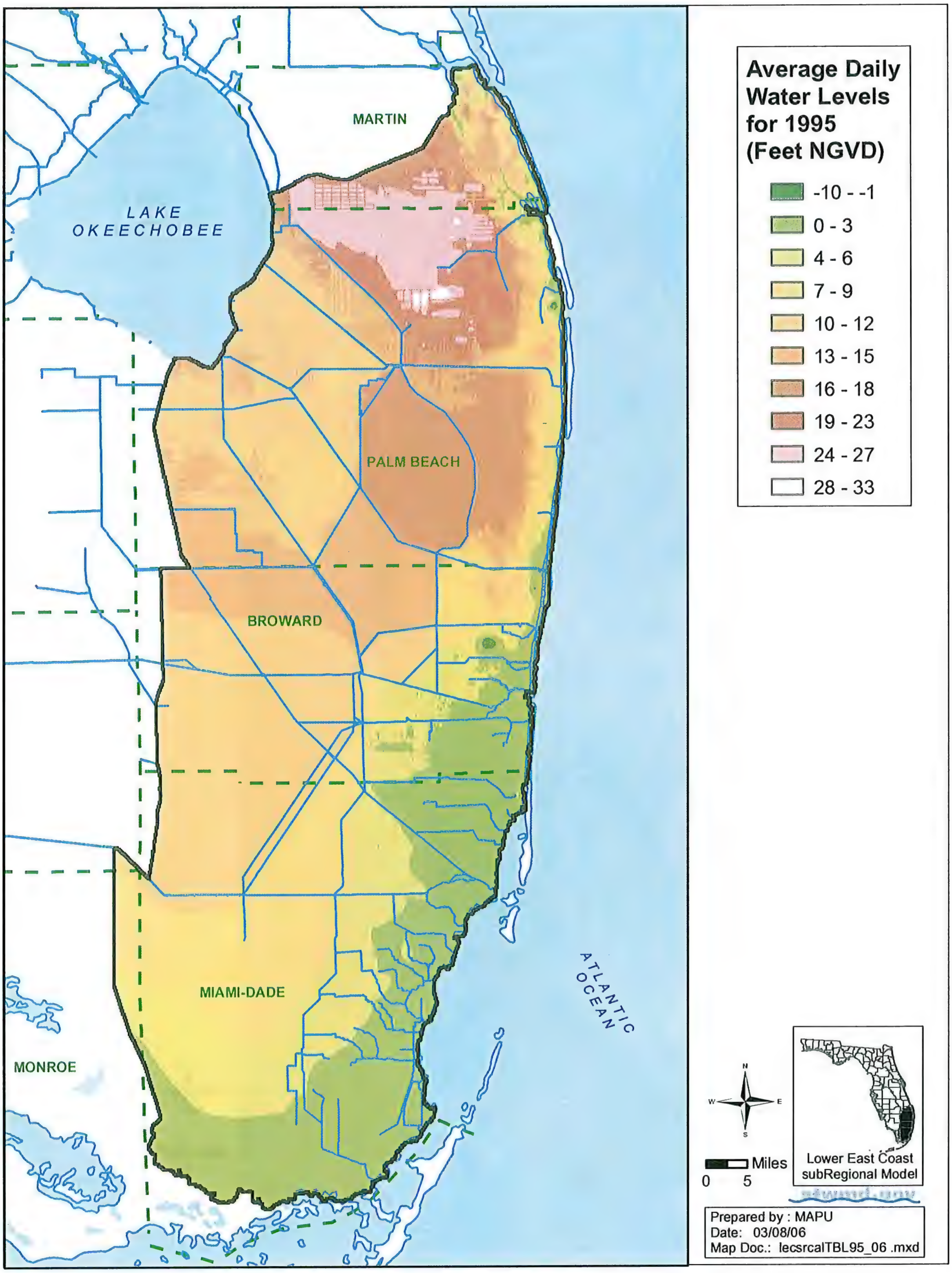


Figure 84. Wet (1995) water level (average daily water levels)

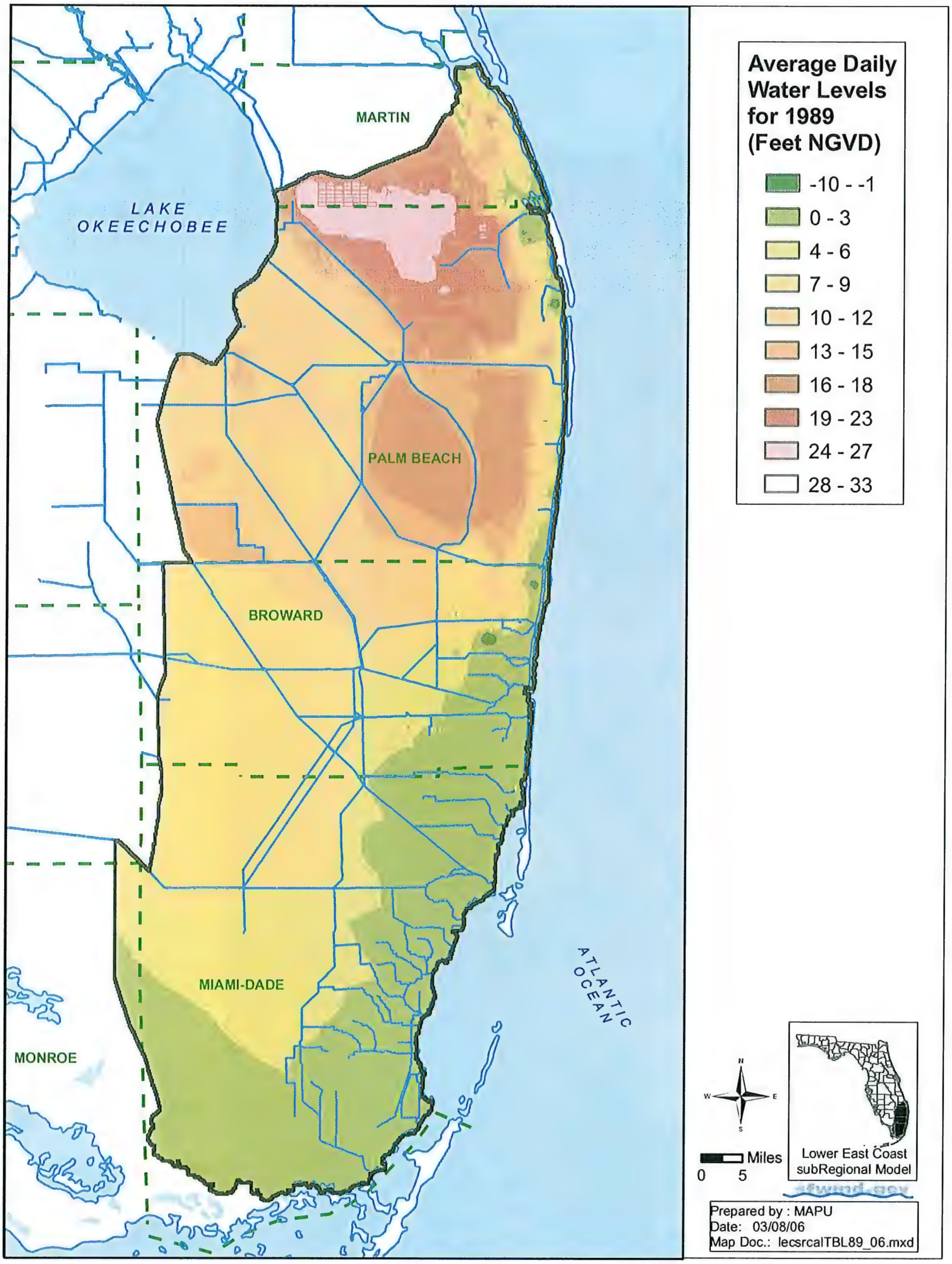


Figure 85. Dry (1989) water level (average daily water levels)

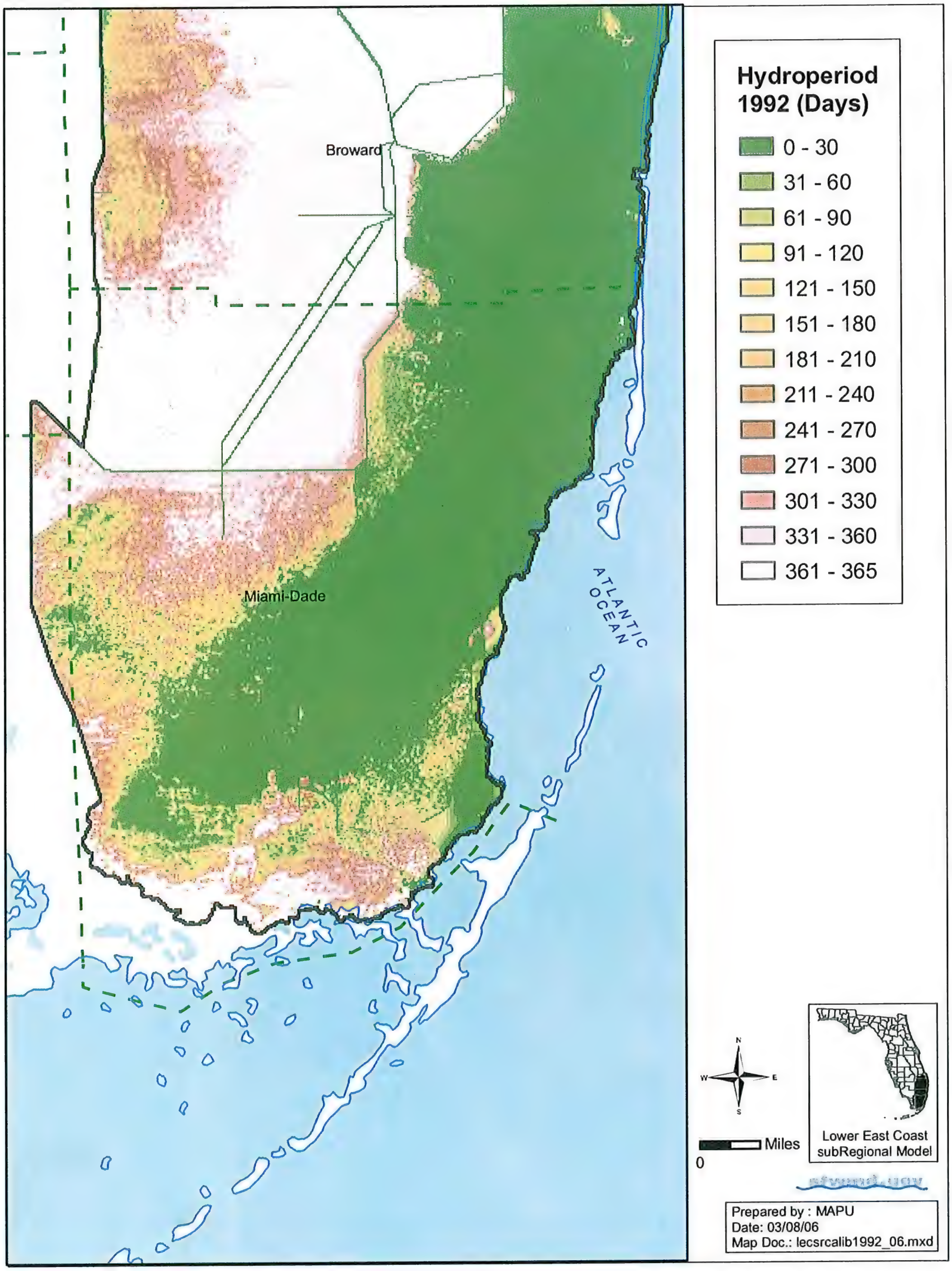


Figure 86. Hydroperiod (ponding) for Average (1992) year

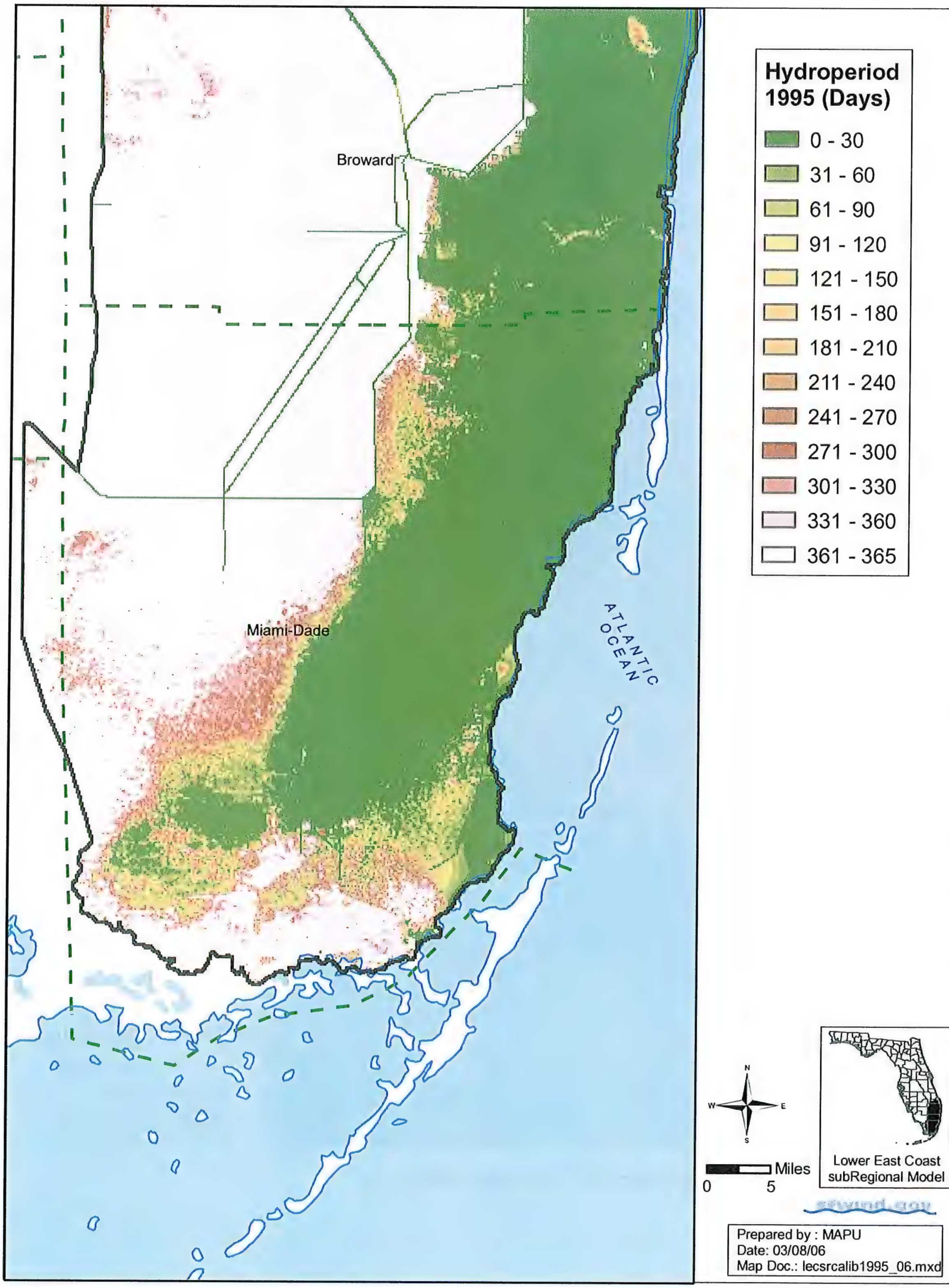


Figure 87. Hydroperiod (ponding) for Wet (1995) year

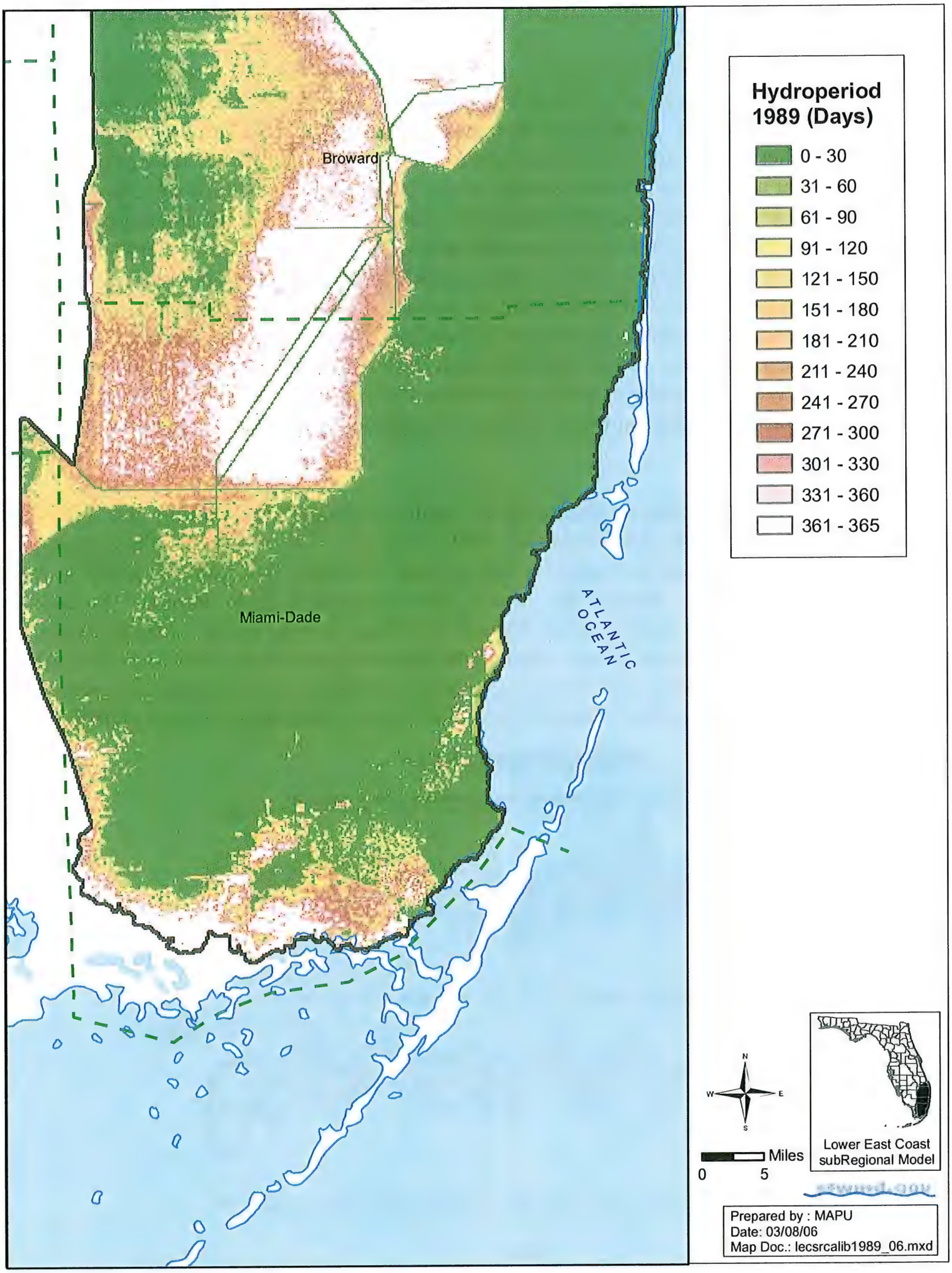


Figure 88. Hydroperiod (ponding) for Dry (1989) year.

Calibration and Simulation for Above Ground Impoundments

Inflows to Water Conservation Areas 1A, 2A and 3A are a combination of water from Lake Okeechobee, which is an external source of water to the model, and outflows to the urban areas. In addition, movement of water through the various compartments is accomplished in a slightly different manner utilizing the redirected flow package. The net flow for a conservation area is equal to the Lake Okeechobee inflows minus the urban outflows. If the Lake Okeechobee inflows are greater than the urban area outflows the net volume for the Conservation area will be positive indicating that water is entering the WCA, if it is negative then water is being removed from the impoundment. This is done for each individual day of the simulation period. Figure XX compares the simulated versus historical net flows for Water Conservation Area 1 of Lake Okeechobee Inflows minus Urban outflows. Urban outflows from Water Conservation Area 1 are primarily to the Lake Worth Drainage District, Broward County and the City of Boca Raton. A similar approach is used to move water to Everglades National Park and the other water Conservation Areas.

Flow from one compartment to another compartment within the WCA's is accomplished utilizing the redirected flow package. The redirected flow package is needed to impose upper limits on the amount of water that can be within a water conservation area to protect the levees that surround it from failing. In addition, operational rules for moving water through the Water Conservation Areas to Everglades National Park can be simulated. **Figures 89** and **90** show the simulated versus historical daily water levels, with a +/- 1 foot error band, for Water Conservation Area Number 1 (Gage 1-9) and Everglades National Park in Northeast Shark River Slough (NESR2).

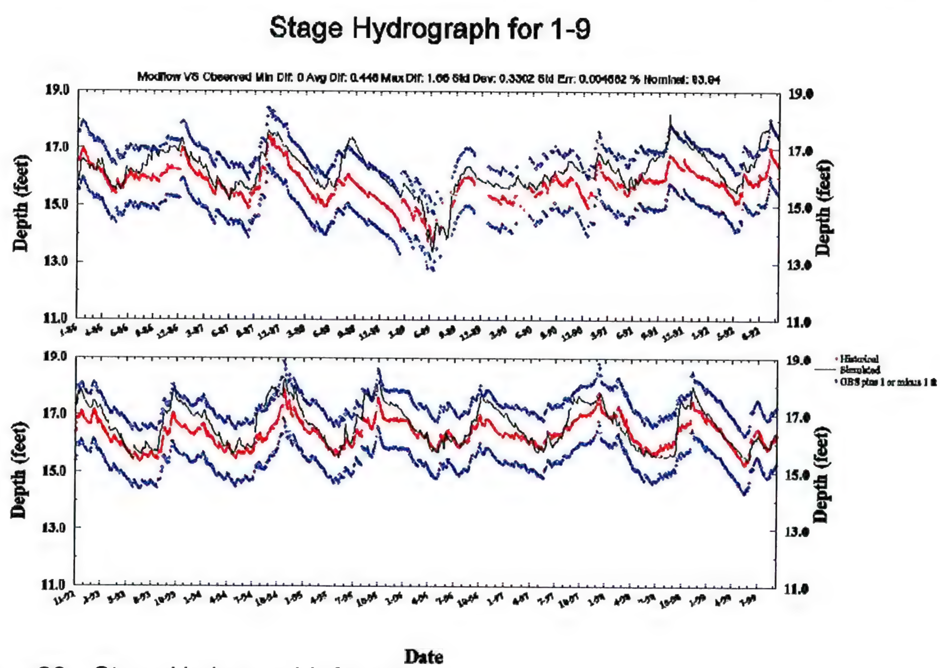


Figure 89. Stage Hydrographh for 1-9

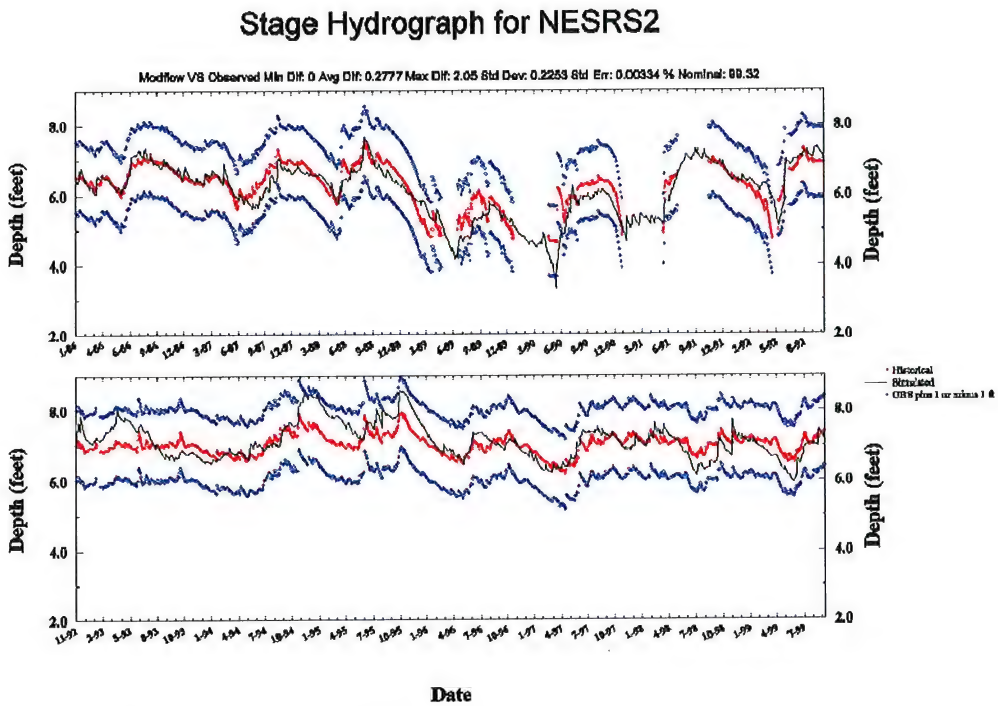


Figure 90. Stage Hydrograph NESRS2

Estimation of Flows to the Loxahatchee River

Estimating flows to the Loxahatchee River is one of the most complex processes in the model as far as conceptualization, design formulation, and calibration. This process will be presented like a case study to fully understand the complexity of the natural and managed components of the system. The Loxahatchee River is a wild and scenic river located in the northeastern portion of the model in Palm Beach and Martin Counties. The contributing basins for the river include the Loxahatchee Slough, the C-18 west sub-basin and Jupiter Farms sub-basin. Flows from these three sub-basins enter the Loxahatchee River via the Lainhart Dam. The river then meanders northward until ultimately discharging to tide at the Jupiter Inlet. **Figure 91** shows the main features associated with the Loxahatchee River.

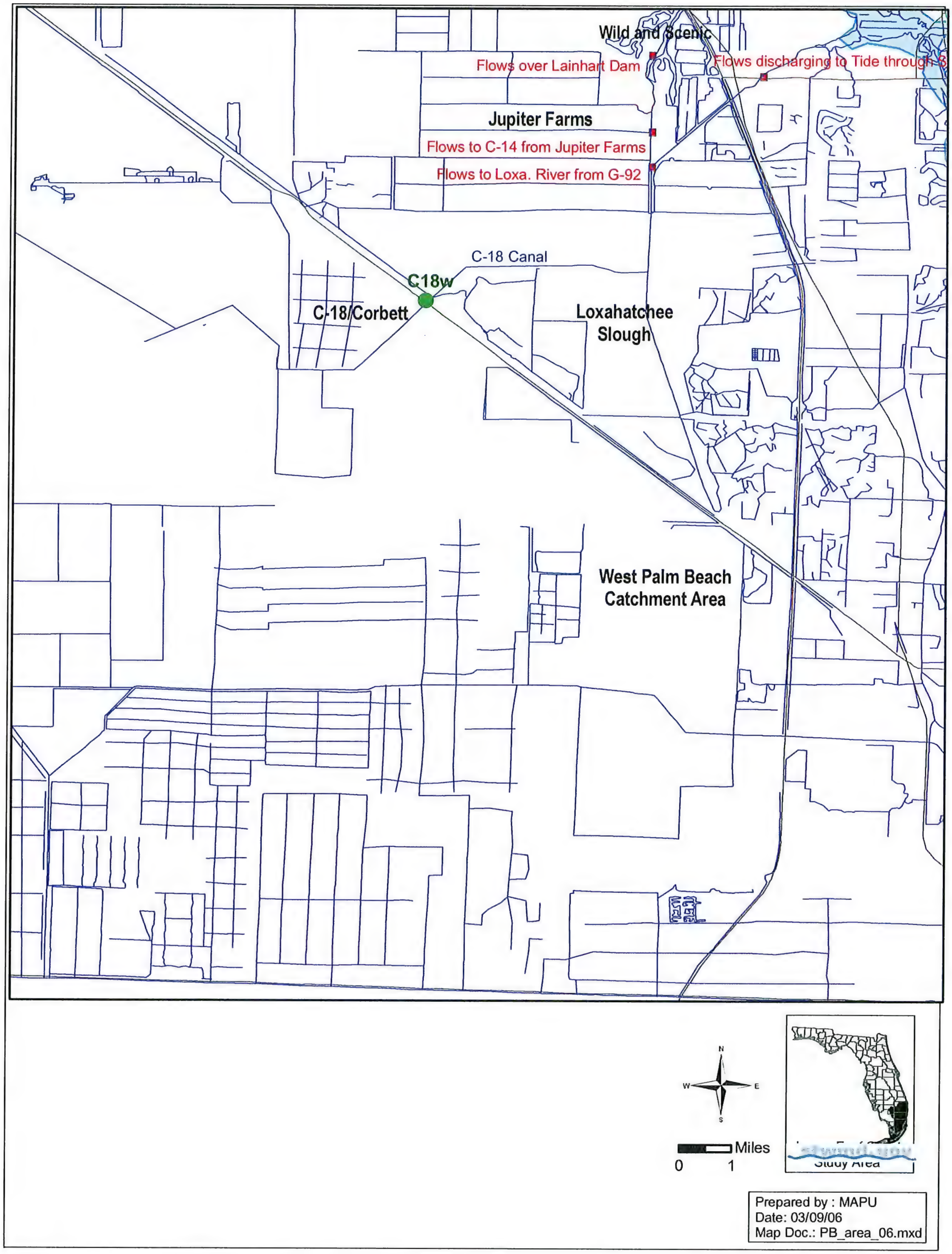


Figure 91. Main Features of Loxahatchee River

The Loxahatchee River itself is simulated in the model as an internal boundary utilizing the Drain package because it is essentially brackish to marine for a significant portion of the river reach. Because of its direct tidal connection, and the need to keep freshwater flowing to the river so it doesn't complete become marine, flows over Lainhart Dam are consider crucial in maintaining the integrity of the river. A simplified approach was utilized to simulate flows over Lainhart Dam by determining flows from the three sub-basins which contribute to the flow. This was accomplished utilizing the wetland and diversion packages. The C-18 west and the Loxahatchee Slough sub-basins are already simulated utilizing the wetlands package. Therefore, there is no preprocessing of rainfall for these areas so recharge in the model is equal to actual rainfall and et is equal to the potential ET for wetlands. The Jupiter Farms sub-basin is a low density urban area so the ET and recharge for this area was modified and treated as wetlands during the recharge preprocessing program so full rainfall would be accounted for in the model in the Jupiter Farms area. The various canals that drain the three sub-basins were simulated using the diversions package instead of the conventional river or drain package. The diversion package allows the user to specify a specific volume of water to move through that reach assuming the upstream and downstream reaches meet the operational criteria specified. Taking the C-18 West weir as an example, water levels upstream would need to be above 17.6 feet NGVD, which is the weir crest, and the down stream reach must be lower than 17.6 for water to move from the C-18 West sub-basin to the Loxahatchee River sub-basin at pre-specified volume of water. The C-18 West sub-basin, because it has several different control elevations, higher than 17.6 feet NGVD, that actually discharge into the C-18 West canal was further sub-divided into 7 smaller sub-basins. The order of operations is as follows. When the water level rose above the control elevations, generally between 19.0 feet and 24.0 feet NGVD, for the upper sub-basins of the C-18 West sub-basin, water would move from these basins into the C-18 West canal reach. If the C-18 West Canal reach rose above 17.6 ft NGVD, water would move into the C-18 Canal. If the water in the C-18 canal was above 13.0 feet NGVD, water would move into the C-14 Canal where it would flow over Lainhart Dam if the C-14 canal was above 11.0 feet. Jupiter Farms flows directly into the C-14 Canal and ultimately over Lainhart Dam. This simplified approach allows the user to move water from one section of the model to another utilizing the overland flow capability of the wetlands package and the operational components of the diversions package essentially creating a "cascade" type approach.

Figures 92, 93, and **94** illustrate the simulated versus historical flow for the three control structures regulating flow to the Loxahatchee River.

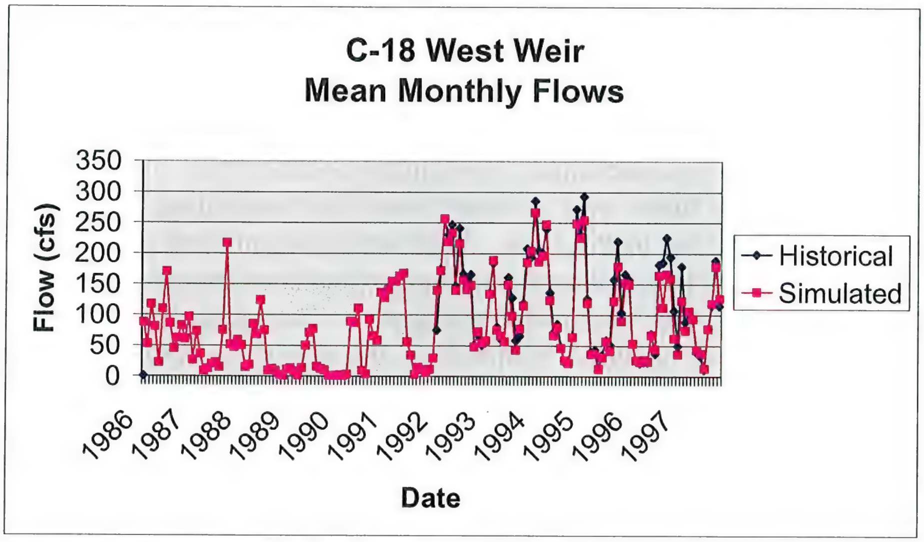


Figure 92. C-18 West Weir Mean Monthly Flows.

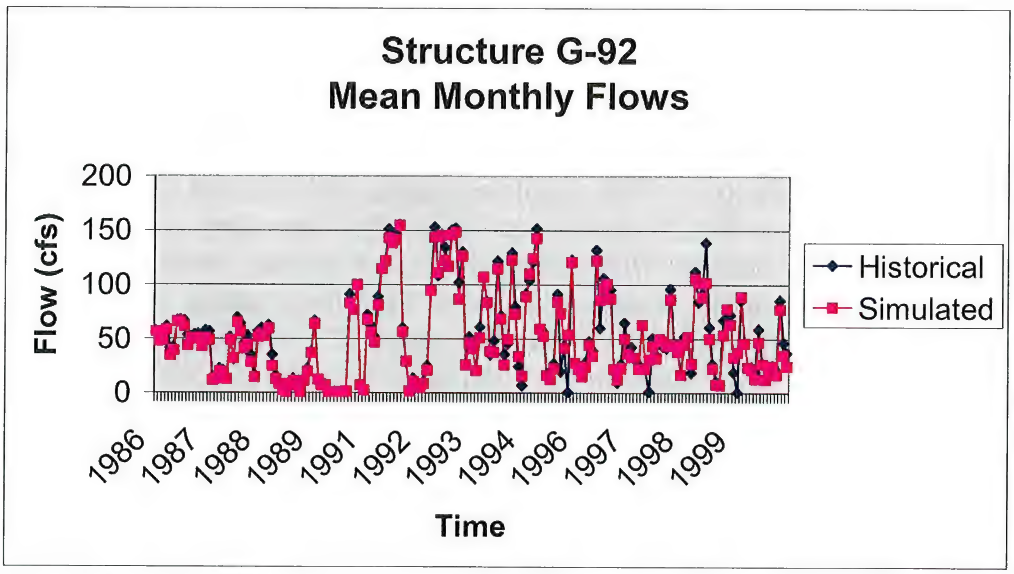


Figure 93. G-92 Mean Monthly Flows.

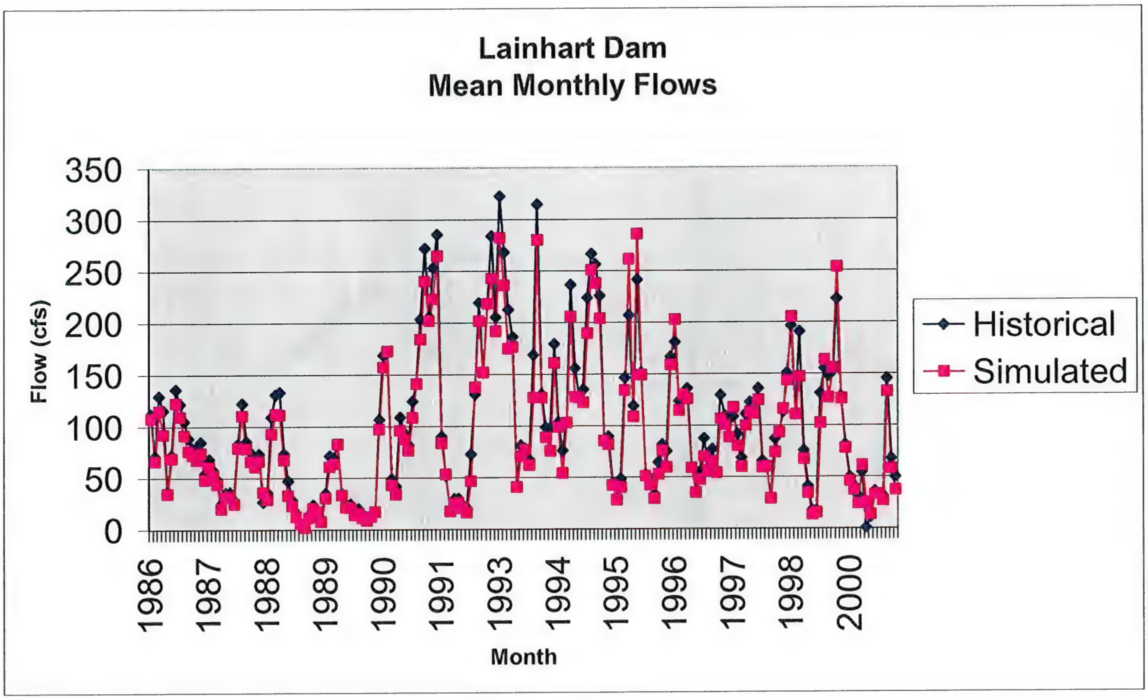


Figure 94. Lainhart Dam Mean Monthly Flows.

Miami-Dade Hialeah/Preston Wellfield Simulation

The Miami-Dade Water and Sewer Authority's Hialeah/Preston wellfield is one of the largest in the State of Florida. Calibration at this wellfield illustrates (**Figure 95)** some of the inherit problems with the model resolution, data collection and the daily stress period. The Hialeah/Preston water treatment plant supplies most of the people in northern Miami-Dade County. It receives water from five different wellfields including the Northwest wellfield (15 production wells), Upper Miami Springs wellfield (12 production wells), the Lower Miami Springs wellfield (8 production wells), the Hialeah wellfield (3 production wells) and the Preston wellfield (7 production wells). Total water treated at the plant is approximately 160 million gallons per day (MGD). The Hialeah, Preston Upper Miami Springs and Lower Miami Springs wellfields are all in close proximity to each other and can be considered as a single wellfield from a regional perspective.

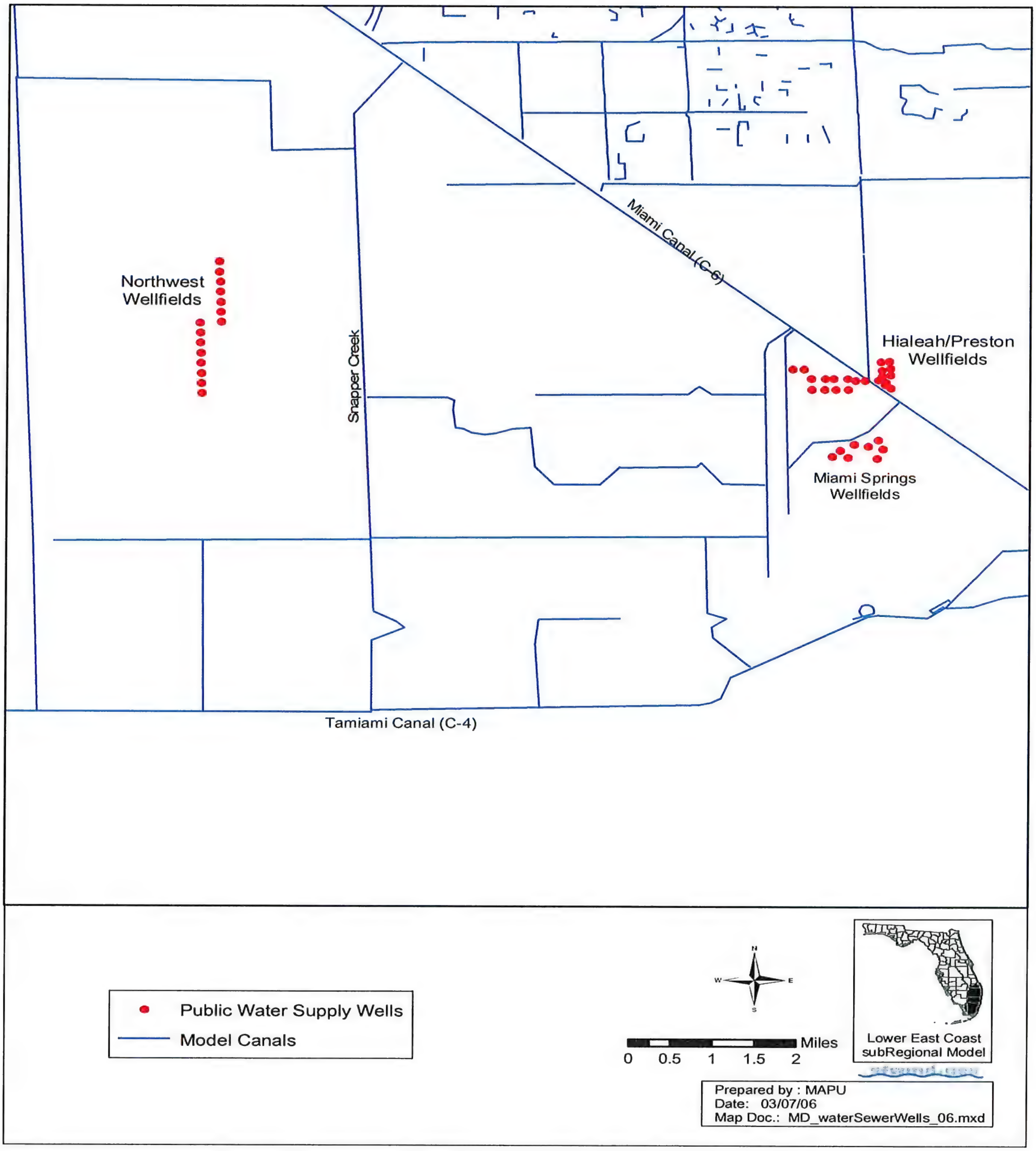


Figure 95. Location of Miami Dade Water and Sewer Authority Wellfields

Historically, municipal utilities were required to submit total monthly raw water withdrawals for each individual treatment plant. In this case, five wellfields are supplying one water treatment plant. Daily data for each wellfield or each production well, is not available. In this case, the water treatment plant is producing approximately 160 MGD but the distribution between wellfields or individual production wells is not known which is problematic. To further complicate things, it appears that a major shift in

wellfield withdrawals occurred midway through the calibration process as shown on **Figure 96**.

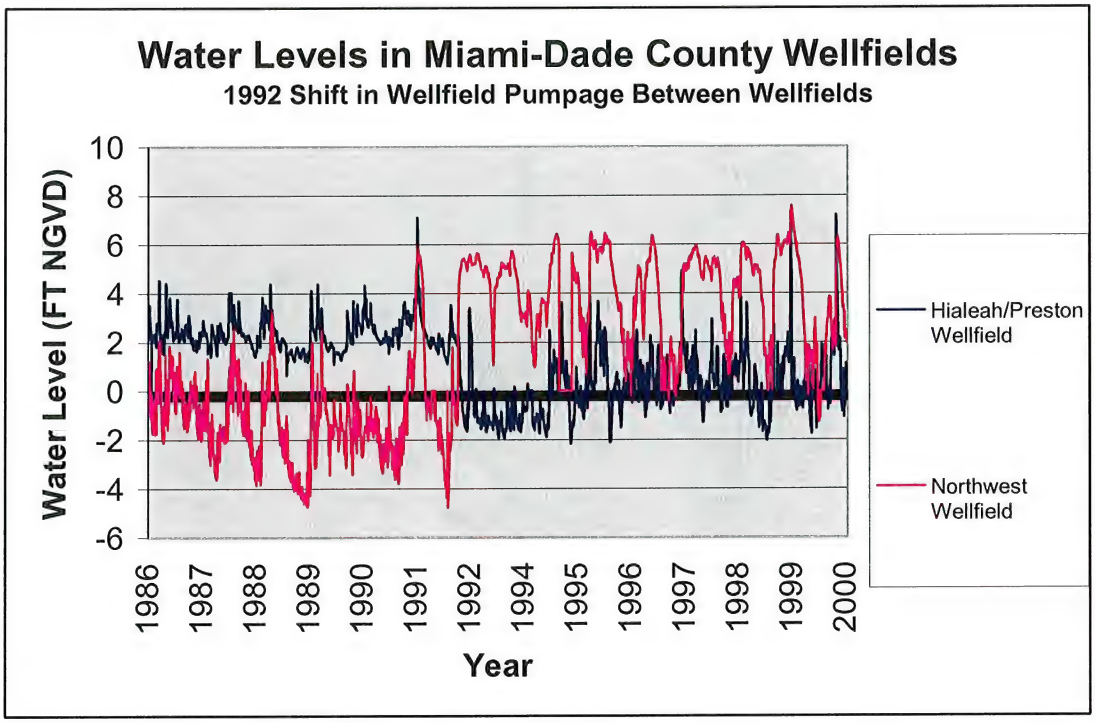


Figure 96. Water Levels in Miami-Dade County Wellfields.

Figure 97 shows the location of the monitoring wells in the vicinity of the Hialeah/Preston and Miami Springs wellfields in Miami-Dade Counties. Observation wells G-3327, G-3328, S-68 and G-3467 are located in close proximity to the wellfields. These wells are reasonable well calibrated as shown in **Figure 98.** However, wells located within the wellfield itself including well S68 which are not as well calibrated as shown in **Figure 99.** One of the main reasons for this is the lack of wellfield and individual well data for the calibration period. The lack of actual daily pumpage data from the individual wells results in a poor calibration closer to the wellfield. This illustrates the point that for larger wellfields, additional data collection, potential rediscritation and partial recalibration of the model is needed before it can be utilized at the local scale.

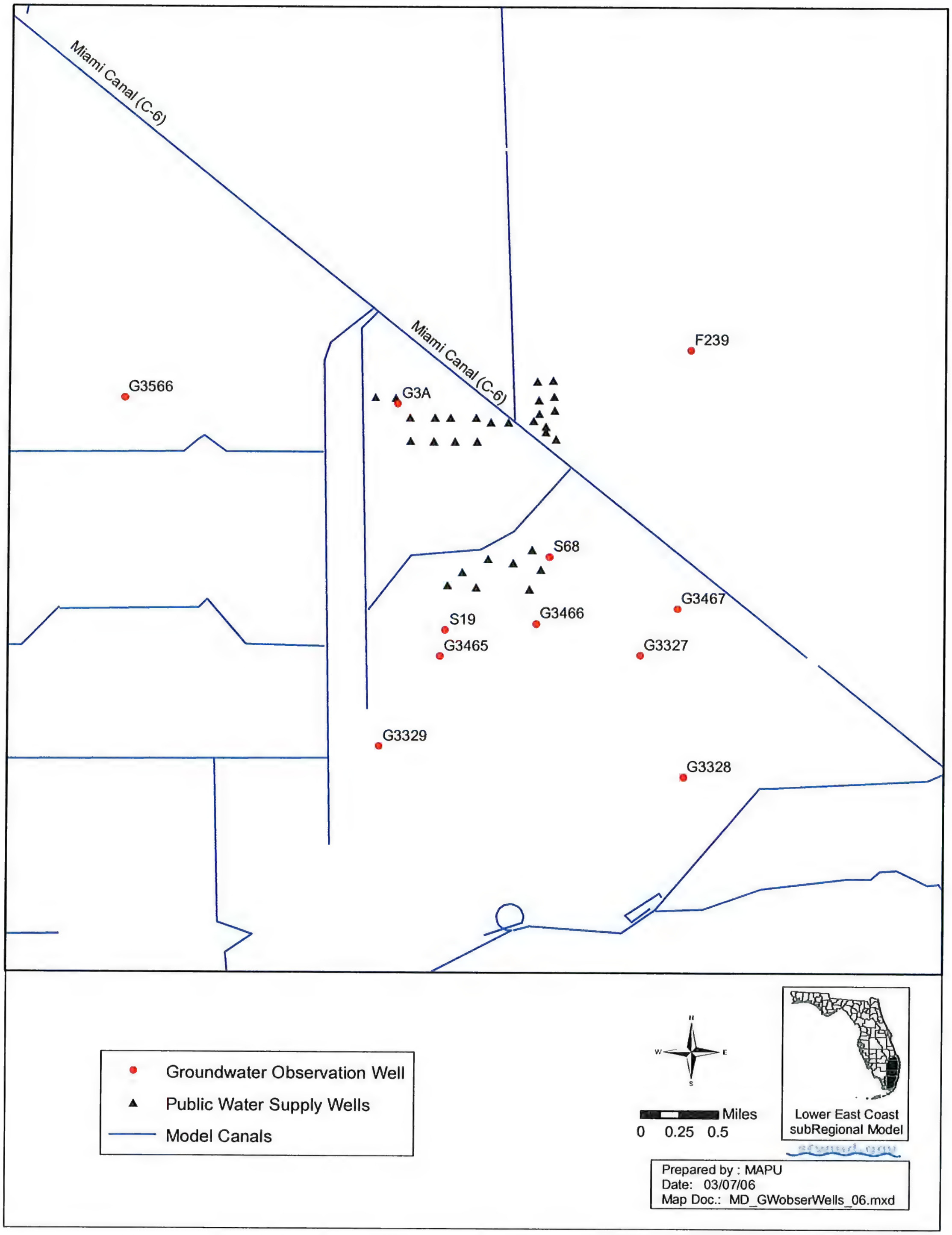


Figure 97. Observation Wells Near X Wellfield.

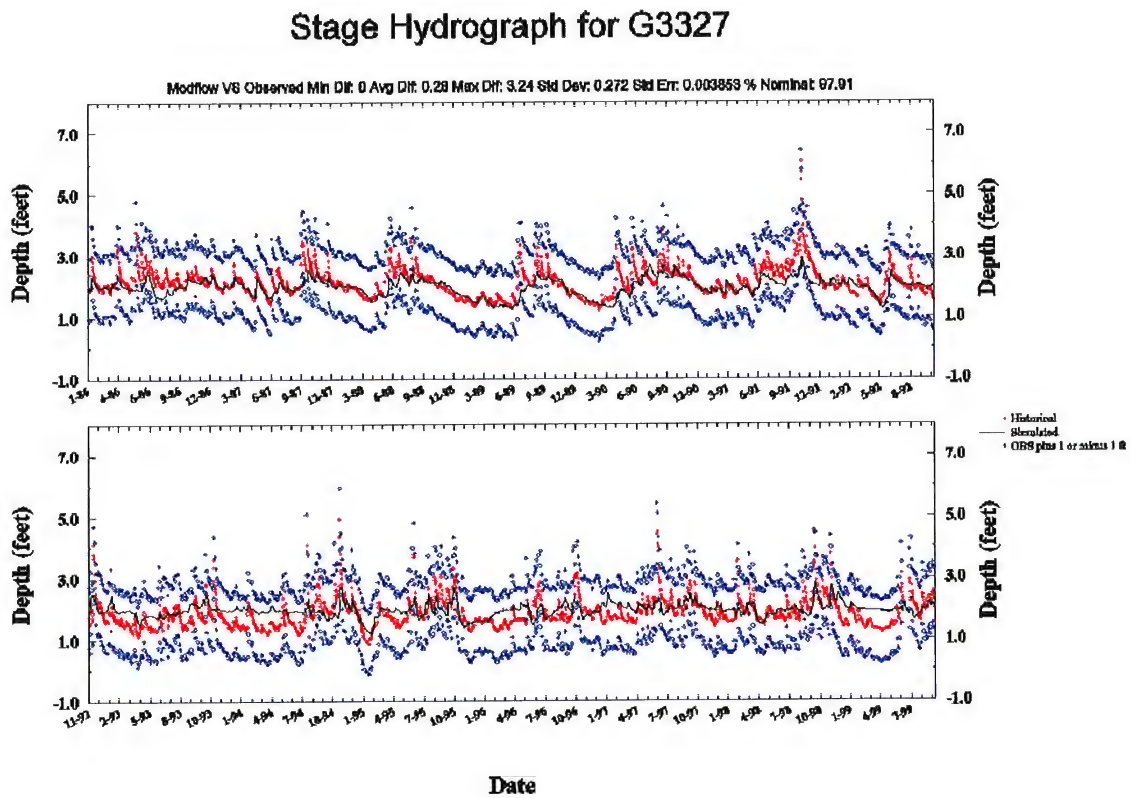


Figure 98. Stage Hydrograph for G3327

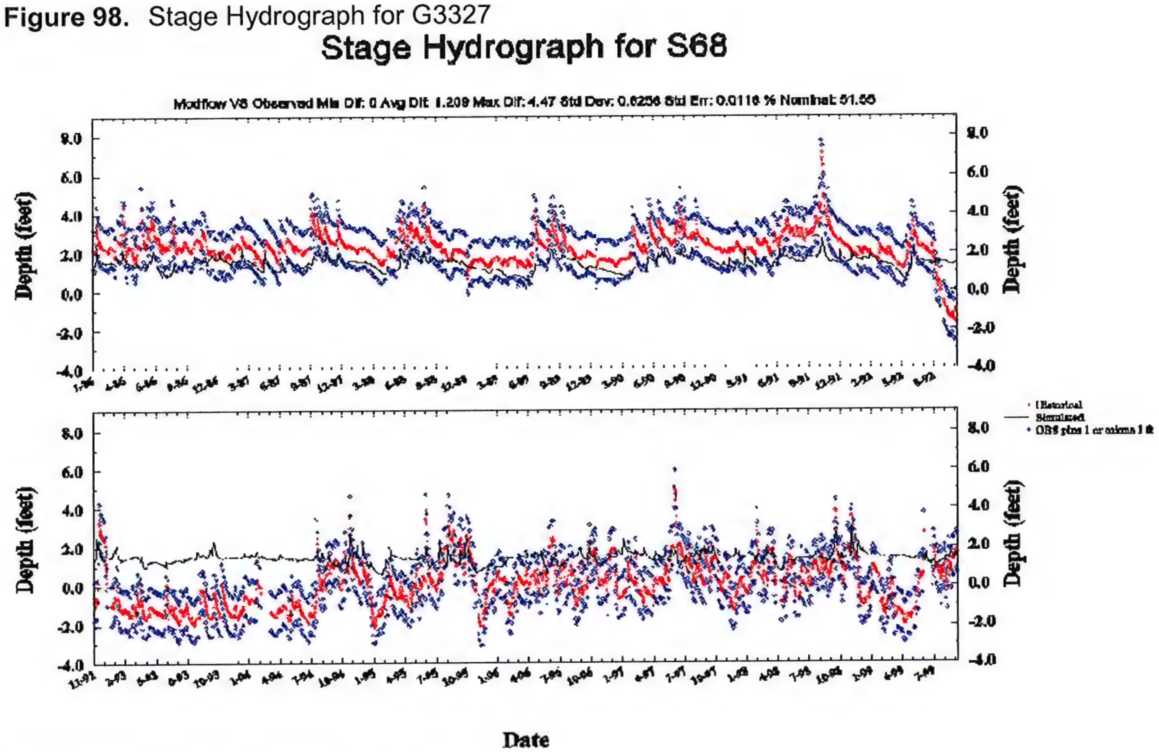


Figure 99. Stage Hydrograph for S68

Volumetric Budget

The volumetric budget for the model area shows the magnitude of the flow components in the active model domain. An analysis of the volumetric budget helps in developing better water management practices and plans. The volumetric budget is also a good indicator of whether the model results are reasonable. A transient state volumetric budget for the LECsR model at the end of the calibration simulation is shown in **Table 14**.

Table 14. LECsR Model Area Volumetric Budget at the End of the Simulation

	Cumulative Volume (ft3)		% In	% Out
	Inflow	Outflow		
Storage	5.0128E+12	5.0541E+12	28.12	28.35
Constant Head	0.0	0.0	0.00	0.00
Wells	1.0000E+9	5.9540E+11	0.01	3.34
Drains	0.0	5.4075E+11	0.00	3.03
River Leakage	3.3327E+12	4.7444E+12	18.70	25.10
ET	0.0	4.4268E+12	0.00	24.83
Head Dependent Boundary	6.1050E+11	1.5291E+12	3.42	8.58
Recharge	6.9891E+12	0.0	39.21	0.00
Redirected Flow	8.1845E+11	8.1845E+11	4.59	4.59
Source/Sink	1.0613E+12	3.8759E+11	5.95	2.17
Totals	1.7826E+13	1.7826E+13	100.00%	100.00%

The largest inflow to the model is rainfall accounting for nearly 40 percent of inflows. Storage changes and river leakage represent the next two largest inflows accounting for 28 percent and 19 percent respectively. Source and sinks, redirected flow, head dependent boundaries and well reuse complete the remainder of inflows total approximately 14 percent. The primary outflows from the model are relatively evenly distributed between storage changes, canal drainage and evapotranspiration. These three account for over 80 percent of the outflows for the model. The remaining outflows are the head dependent boundaries, redirected flow, sources and sinks, and wells which are only 3 percent of the entire water budget.

VERIFICATION

Calibration is carried out for a period presenting different hydrological conditions. Verification serves to test whether the set of parameters selected during the calibrations are in fact suitable to represent a different period. In the LECsR Model project the period

1986-1999 has been selected as the calibration period and the period 1999-2000 is the verification period. In principle, the model calibration results should remain relatively unchanged for the two periods.

The overall model statistics for the verification run do not change drastically from the calibration run as shown in Table **15**.. The global standard deviation was less for the verification run than for the calibration run although the mean absolute error and the root mean squared error are slightly improved.

Table 15. Calibration Results for the Entire Model Domain (195 observation wells) for the verification period (1995-2000)

Statistical criteria	**Verification Range**	**Calibration Range**
RES Global	99%	100 %
STD Global	71 %	80 %
MIN/MAX Global	96 %	99 %
+/- 1.0 Global	88 %	87 %
ME Global	0.11 ft	0.00 ft
MAE Global	0.54 ft	0.55 ft
RMSE Global	0.67 ft	0.70 ft

In general the wells that were consider calibrated after the calibration run remained calibrated for the verification run. No noticeable improvement in the wells consider not calibrated was observed in the verification scenario. **Figure 100** shows the difference of the mean absolute error between the calibrated and verified simulation periods for each well. Approximately 95 percent of the wells are within a change of +/- 0.5 feet with approximately 85 percent of the wells changing less than 0.25 feet. Considering the verification period was one tenth in length as the calibration period, the results suggest that the model appears to be robust in its ability to simulate conditions adequately.

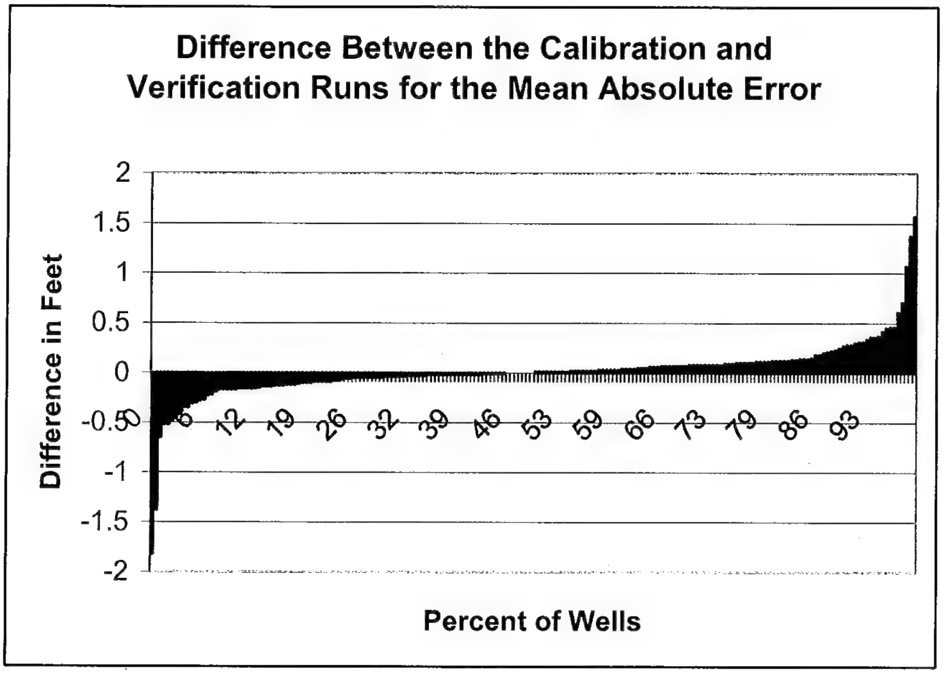


Figure 100. Difference Between Calibration and Verification Runs for the Mean Absolute Error.

Table 16. Statistics for Verification Period.

Well	Residual	Std Dev	Min/Max	1 Foot	ME	MAE	RMS
1-7	100.00	70.00	86.05	98.60	-0.24	0.46	0.51
1-9	100.00	81.16	88.84	100.00	-0.28	0.38	0.42
2A-17	100.00	89.77	100.00	90.93	0.19	0.36	0.48
2B-Y	100.00	62.09	100.00	98.84	0.39	0.43	0.49
ANGEL	100.00	79.30	100.00	79.53	0.50	0.63	0.88
EVER1	100.00	70.88	95.23	100.00	-0.12	0.21	0.28
EVER2A	100.00	87.13	96.04	100.00	-0.14	0.14	0.15
EVER2B	100.00	96.09	100.00	100.00	-0.14	0.16	0.19
EVER3	100.00	96.05	100.00	100.00	-0.10	0.14	0.18
EVER4	100.00	89.07	99.53	100.00	-0.13	0.18	0.23
F239	98.37	85.12	100.00	79.77	-0.32	0.69	0.92
F291	97.38	94.76	100.00	94.05	-0.02	0.52	0.77
F319	98.83	95.33	96.26	97.66	0.18	0.23	0.54
F358	98.14	85.58	86.98	90.23	0.54	0.54	0.76
F45	96.04	83.92	83.45	80.89	0.57	0.61	0.92
FROGP	99.30	96.51	100.00	98.84	0.15	0.27	0.36
G1074B	100.00	13.24	100.00	6.38	-4.45	4.65	4.96
G1166	98.75	94.99	100.00	97.24	0.01	0.21	0.40
G1183	98.99	85.32	100.00	95.95	-0.09	0.29	0.46
G1213	99.07	73.60	100.00	80.61	-0.36	0.53	0.68
G1220	100.00	96.68	100.00	97.95	0.04	0.24	0.33
G1221	99.07	82.09	100.00	91.16	-0.20	0.38	0.55

Well	Residual	Std Dev	Min/Max	1 Foot	ME	MAE	RMS
G1223	95.45	66.84	72.19	95.45	0.28	0.39	0.48
G1224	99.24	96.19	100.00	96.70	-0.06	0.30	0.41
G1225	97.44	89.77	100.00	87.67	0.46	0.52	0.81
G1226	98.75	96.01	100.00	95.76	-0.07	0.44	0.64
G1260	91.57	65.11	86.18	28.57	1.55	1.55	1.74
G1315	99.30	97.91	99.77	96.98	-0.01	0.20	0.37
G1316	98.60	90.47	100.00	97.67	-0.12	0.30	0.40
G1362	97.29	94.85	100.00	95.39	0.27	0.37	0.77
G1363	97.67	95.58	100.00	95.81	-0.01	0.37	0.66
G1473	97.59	93.98	100.00	93.98	-0.01	0.46	0.72
G1486	98.84	96.28	100.00	97.67	0.12	0.22	0.49
G1487	98.35	93.63	100.00	98.35	-0.01	0.26	0.36
G1488	100.00	98.60	95.35	100.00	0.05	0.31	0.35
G1636	98.14	91.86	100.00	97.21	0.13	0.27	0.37
G1637	97.67	60.70	100.00	94.65	0.52	0.54	0.63
G2031	98.60	83.02	100.00	97.21	-0.04	0.31	0.44
G2032	100.00	57.67	93.49	81.63	-0.27	0.56	0.75
G2033	97.21	73.95	98.37	93.02	0.07	0.44	0.68
G2034	95.58	75.35	92.33	86.51	0.21	0.53	0.71
G2035	98.37	95.58	100.00	95.81	0.02	0.38	0.61
G2147	100.00	83.01	100.00	72.73	0.12	0.70	0.85
G2395	100.00	50.93	100.00	10.00	-2.57	3.05	3.41
G2739	100.00	42.86	52.38	85.71	-0.60	0.57	0.66
G2852	100.00	70.33	100.00	60.05	-0.28	0.97	1.23
G2866	100.00	0.00	100.00	0.00	5.32	5.09	5.09
G3074	99.07	60.23	100.00	54.19	-1.14	1.28	1.63
G3253	100.00	94.72	100.00	47.24	0.22	1.18	1.39
G3259A	100.00	92.48	100.00	72.43	0.46	0.73	0.87
G3264A	100.00	99.18	100.00	99.73	0.18	0.46	0.53
G3272	100.00	69.32	100.00	91.80	0.42	0.46	0.58
G3273	96.05	63.72	100.00	85.12	0.42	0.51	0.65
G3327	98.76	92.24	100.00	96.89	0.22	0.28	0.47
G3328	98.14	95.58	100.00	97.91	0.11	0.22	0.41
G3329	97.67	92.79	97.91	96.05	0.37	0.39	0.70
G3353	100.00	83.95	96.51	100.00	-0.16	0.21	0.29
G3355	97.14	80.19	99.05	94.27	0.31	0.33	0.48
G3356	90.70	70.47	90.00	90.93	0.42	0.43	0.56
G3437	100.00	57.42	100.00	68.61	0.69	0.74	0.89
G3439	100.00	75.50	99.01	90.35	-0.57	0.60	0.66
G3465	100.00	95.35	100.00	93.26	0.07	0.51	0.84
G3466	100.00	42.86	100.00	100.00	0.44	0.43	0.50
G3467	100.00	47.62	100.00	100.00	0.24	0.23	0.27
G3473	100.00	80.95	100.00	100.00	-0.01	0.09	0.12
G3549	100.00	42.86	100.00	100.00	0.09	0.15	0.20
G3550	100.00	28.57	85.71	100.00	-0.15	0.18	0.20
G3551	100.00	93.66	100.00	98.12	-0.07	0.21	0.31
G3552	100.00	91.40	100.00	96.98	0.25	0.30	0.40

Well	Residual	Std Dev	Min/Max	1 Foot	ME	MAE	RMS
G3553	100.00	67.18	100.00	88.11	0.60	0.60	0.68
G3554	100.00	33.23	100.00	67.41	0.99	0.99	1.05
G3555	100.00	85.57	100.00	89.80	0.52	0.52	0.73
G3556	100.00	71.15	100.00	90.14	0.56	0.56	0.64
G3557	100.00	95.77	100.00	97.42	0.04	0.22	0.34
G3558	100.00	98.57	100.00	100.00	-0.05	0.22	0.29
G3559	100.00	96.05	100.00	98.37	0.09	0.16	0.27
G3560	100.00	86.49	100.00	92.89	0.35	0.37	0.52
G3561	100.00	49.15	100.00	87.89	0.70	0.70	0.86
G3563	100.00	0.00	100.00	100.00	0.68	0.64	0.67
G3564	100.00	28.57	100.00	100.00	0.51	0.49	0.53
G3565	100.00	0.00	100.00	95.24	0.81	0.77	0.78
G3566	100.00	0.00	100.00	52.38	1.02	0.99	1.08
G3567	100.00	0.00	100.00	100.00	0.62	0.59	0.59
G3568	100.00	61.90	95.24	100.00	-0.20	0.24	0.31
G3570	100.00	0.00	100.00	85.71	0.89	0.85	0.86
G3572	100.00	97.00	100.00	99.46	-0.03	0.18	0.36
G3576	100.00	51.40	100.00	98.84	0.44	0.43	0.46
G3619	100.00	89.41	100.00	99.76	0.21	0.23	0.28
G3620	100.00	91.81	100.00	99.52	0.06	0.16	0.24
G3621	100.00	94.39	100.00	99.30	-0.09	0.17	0.23
G3622	100.00	93.02	100.00	95.35	0.11	0.39	0.51
G3626	100.00	54.16	100.00	77.91	-0.58	0.73	0.83
G3627	100.00	96.91	100.00	97.39	-0.13	0.32	0.56
G3628	100.00	85.41	100.00	92.58	0.29	0.39	0.58
G3676	100.00	0.00	4.76	100.00	-0.34	0.32	0.34
G3A	100.00	14.29	0.00	19.05	-1.66	1.63	1.73
G551	98.17	55.87	100.00	41.25	-0.88	1.19	1.42
G553	98.37	91.86	93.49	95.12	0.46	0.47	0.77
G561	99.27	90.71	100.00	96.58	0.19	0.33	0.46
G580A	97.67	94.88	99.07	95.58	0.25	0.28	0.68
G614	98.11	96.22	100.00	96.22	0.17	0.35	0.81
G617	91.95	71.22	81.22	80.00	0.57	0.58	0.90
G620	100.00	96.51	100.00	100.00	-0.03	0.32	0.37
G757A	97.44	96.28	100.00	96.28	0.20	0.29	0.68
G789	97.91	76.05	100.00	96.05	-0.37	0.53	0.63
G852	97.67	88.14	100.00	90.23	0.26	0.40	0.72
G853	100.00	78.13	100.00	62.41	0.32	0.99	1.26
G855	97.21	88.37	100.00	93.26	0.32	0.38	0.57
G860	99.30	93.94	98.60	98.60	0.11	0.21	0.49
G864	98.37	87.67	100.00	90.70	0.45	0.48	0.74
G864A	85.71	57.14	100.00	85.71	0.42	0.46	0.61
G968	98.60	76.28	94.88	96.98	0.57	0.57	0.63
G970	97.64	83.92	93.38	97.64	0.24	0.31	0.40
G973	99.51	94.09	100.00	98.03	-0.02	0.23	0.36
G975	100.00	99.53	93.49	99.53	-0.18	0.32	0.38
G976	100.00	99.76	100.00	99.52	0.15	0.35	0.43

Well	Residual	Std Dev	Min/Max	1 Foot	ME	MAE	RMS
HUMBLE	97.91	95.81	100.00	97.44	0.01	0.27	0.50
JD12	100.00	49.30	98.37	95.81	0.44	0.47	0.57
JD26	100.00	21.86	75.58	68.84	-0.96	0.98	1.18
JD6	100.00	2.79	70.93	17.91	-1.66	1.66	1.80
JDMW1	100.00	96.71	89.87	52.15	-0.83	0.94	1.06
JDMW3	100.00	100.00	100.00	61.29	-0.21	0.74	0.86
KROME	100.00	8.68	100.00	86.53	0.71	0.72	0.76
L30L67A	100.00	57.52	94.69	100.00	-0.22	0.24	0.29
L67A	100.00	16.81	100.00	100.00	0.61	0.60	0.61
M1024	100.00	47.62	100.00	100.00	0.19	0.20	0.23
M1234	100.00	0.00	100.00	14.29	1.38	1.32	1.36
NESRS1	99.75	48.88	67.49	99.75	0.06	0.35	0.43
NESRS2	100.00	60.70	76.98	100.00	0.16	0.29	0.33
NESRS4	95.58	55.81	66.05	97.67	0.34	0.44	0.52
NESRS5	92.56	56.05	63.95	97.44	0.40	0.45	0.55
NP112	100.00	15.93	100.00	98.23	0.67	0.67	0.73
NP127	100.00	55.75	91.15	100.00	-0.27	0.32	0.36
NP146	100.00	90.18	91.96	100.00	-0.16	0.18	0.21
NP158	84.21	3.95	100.00	84.21	0.79	0.78	0.81
NP-201	100.00	100.00	100.00	100.00	0.19	0.31	0.38
NP-202	99.07	95.81	99.77	98.60	0.32	0.42	0.48
NP-203	99.77	86.05	96.51	100.00	0.24	0.35	0.43
NP-205	100.00	87.67	100.00	87.67	-0.08	0.64	0.76
NP-206	99.30	48.14	100.00	65.58	0.44	0.70	0.84
NP311	100.00	15.93	100.00	100.00	0.52	0.52	0.58
NP-33	93.02	61.40	68.60	96.98	0.44	0.46	0.56
NP-35	97.35	93.81	99.12	99.12	0.00	0.12	0.21
NP-36	80.09	53.32	55.45	77.73	0.57	0.58	0.72
NP-38	99.12	97.36	100.00	99.71	0.16	0.19	0.23
NP-44	86.41	67.96	100.00	91.26	0.23	0.32	0.49
NP-46	98.97	81.28	100.00	98.72	0.24	0.34	0.41
NP-62	99.07	78.14	100.00	95.81	0.25	0.48	0.57
NP-67	99.30	77.67	98.14	98.37	0.15	0.31	0.40
NPA13	100.00	13.27	100.00	100.00	0.05	0.37	0.42
NPCHP	100.00	85.85	93.40	100.00	0.20	0.20	0.22
NPCR2	100.00	38.05	100.00	100.00	0.28	0.30	0.36
NPCR3	100.00	42.11	100.00	100.00	0.34	0.35	0.43
NPCY2	100.00	72.32	91.07	100.00	-0.04	0.18	0.22
NPCY3	100.00	49.55	100.00	100.00	0.23	0.24	0.28
NPDO1	100.00	67.26	96.46	100.00	-0.14	0.26	0.28
NPDO2	100.00	74.34	100.00	100.00	0.11	0.24	0.34
NPEP1	100.00	91.80	90.16	100.00	-0.11	0.13	0.14
NPEPS	100.00	70.00	99.30	100.00	-0.12	0.21	0.28
NPEV6	100.00	98.28	100.00	100.00	0.07	0.11	0.14
NPEV7	100.00	48.65	100.00	100.00	0.19	0.19	0.23
NPEV8	100.00	94.69	100.00	100.00	-0.18	0.19	0.21
NPN10	100.00	87.99	99.88	94.66	0.36	0.49	0.59

Well	Residual	Std Dev	Min/Max	1 Foot	ME	MAE	RMS
NPN14	100.00	31.86	100.00	89.38	0.61	0.61	0.66
NPNTS1	97.35	14.16	100.00	96.46	0.68	0.70	0.76
NPP37	100.00	94.16	100.00	100.00	-0.04	0.19	0.26
NPROB	100.00	94.69	100.00	96.46	-0.14	0.45	0.65
NP-TSB	100.00	92.09	100.00	89.07	0.43	0.63	0.70
NPTSH	100.00	61.61	89.29	100.00	-0.15	0.19	0.25
PB1491	96.74	38.14	100.00	34.88	1.03	1.33	1.56
PB1639	100.00	50.93	100.00	33.02	-0.01	1.71	2.00
PB1642	100.00	90.60	100.00	88.51	-0.22	0.50	0.72
PB1661	100.00	88.49	100.00	95.44	0.05	0.40	0.55
PB1662	100.00	59.57	100.00	68.79	-0.47	0.78	0.96
PB1680	100.00	89.30	100.00	89.53	0.43	0.54	0.69
PB1684	100.00	67.33	100.00	96.29	0.35	0.38	0.51
PB445	100.00	77.52	100.00	94.85	-0.27	0.35	0.46
PB561	100.00	72.33	98.84	63.72	-0.53	0.88	1.11
PB565	97.44	82.33	78.60	77.44	0.78	0.81	1.12
PB683	99.30	70.00	94.65	72.56	-0.34	0.80	1.08
PB685	100.00	96.73	100.00	93.69	-0.02	0.33	0.56
PB689	100.00	70.70	100.00	89.07	-0.33	0.51	0.70
PB732	99.53	92.09	100.00	92.09	0.27	0.47	0.60
PB809	99.53	20.23	100.00	26.74	-1.20	1.25	1.35
PB831	100.00	87.44	100.00	89.77	-0.26	0.49	0.63
S18	97.70	94.83	100.00	95.98	0.07	0.30	0.59
S182	98.80	94.26	95.69	98.09	0.25	0.27	0.59
S19	98.49	92.96	100.00	89.70	-0.09	0.60	0.85
S196A	98.60	95.58	95.12	96.05	0.00	0.38	0.64
S329	99.07	93.72	92.79	82.09	0.60	0.64	0.80
S68	98.32	82.01	100.00	62.35	-0.48	0.99	1.27
SWEV5A	100.00	51.33	96.46	100.00	-0.36	0.37	0.42
SYLVA	96.05	86.05	99.30	82.09	0.59	0.60	1.03
WCA363	100.00	94.99	100.00	88.65	-0.25	0.56	0.65
WPBCA	100.00	60.61	100.00	93.47	0.14	0.55	0.64

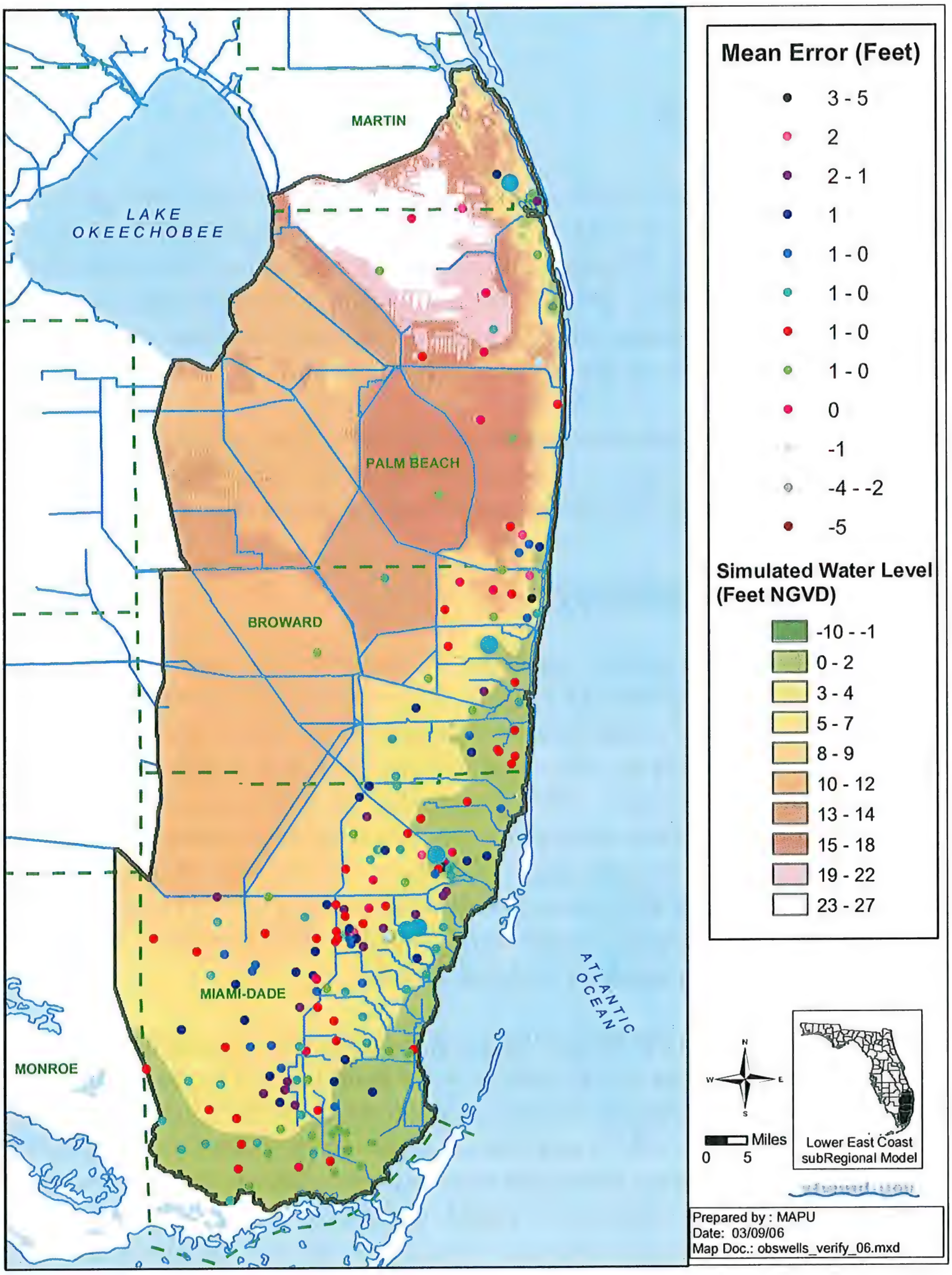


Figure 101. Simulated water levels and mean error for verification run.

SENSITIVITY ANALYSIS

After a groundwater flow model has been calibrated, a final sensitivity analysis is performed. Sensitivity analysis is defined as "a quantitative evaluation of the impact of variability or uncertainty in model inputs on the degree of calibration of a model and on its results or conclusions" (ASTM, 2002). Sensitivity runs were conducted to test the magnitude of the model's response on the range of simulated outputs to changes in stresses, aquifer parameters, and surface-groundwater interaction.

The purpose of the sensitivity analysis is to vary input parameters within an acceptable range. Acceptable ranges of variation for input parameters were decided based on model output response and on expected error on input parameters.

Parameters and Methodology

The sensitivity of the output variables to variations in input parameters is estimated by the traditional approach of varying one parameter at a time by a constant factor. For each parameter, two model runs were completed by increasing and decreasing the value. The simulation period for the sensitivity analysis was within the calibration period, January 1986 to December 1995, which has a wide range of hydrologic conditions ranging from very dry to average to very wet hydrologic periods. Parameters tested included recharge, ET maximum rate, ET surface, ET extinction depth, horizontal hydraulic conductivity (HK) for all layers, vertical conductance (VCONT), specific yield (SY), river and drain conductance, general head boundary (GHB) conductance. The range of values tested for each parameter is shown in Table 17.

Several parameters specific to the Wetlands package were also tested, including Kadlec coefficient, specific yield of the surface water body (SYWTL), specific yield of the muck/peat (SYMUC), horizontal hydraulic conductivity of the muck/aquifer layer underneath the water body (HYMUC) and bottom elevation of surface water (ZBOTT). Kadlec coefficient in wetland areas represents vegetative resistance to flow or drag forces on moving water as it flows through wetland vegetation. The soil/aquifer layer underneath the water body is simulated as part of the top layer (e.g., surface water body), as an independent confined/unconfined layer, or as part of the aquifer underneath.

Table 17. Sensitivity Analysis Parameters for LECsR Transient Simulation

Condition varied	Corresponding Change(1)	
	Up	Down
Stresses and related variables		
ET maximum rate	× 1.5	× 0.7
ET surface elevation	+ 2.0 ft	- 2.0 ft
ET extinction depth	× 2.0	× 0.5
Recharge	× 1.5	× 0.7
Aquifer parameters		
HK layer 1 (aquifer)	× 2.5	× 0.2
HK layers 2 and 3	× 5.0	× 0.2
VCONT layer 1	× 10.0	× 0.5
VCONT layer 2	× 10.0	× 0.1
SY layer 1 (aquifer)	+ 0.1	- 0.1
Surface-ground water interaction		
Kadlec coefficient	×1.5	×0.7
SYWTL	+0.3	- 0.3
SYMUC	+ 0.3	- 0.3
HKMUC	× 2	× 0.1
Anisotropy factor in HKMUC	× 20.0	× 0.02
ZBOTT	+2.0 ft	-2.0 ft
GHB conductance	× 100.0	× 0.01
Drain conductance	× 5.0	× 0.1
River conductance	× 5.0	× 0.1

(1) Change from calibrated value: × or parameter multiplied by a factor of;
+/- or parameter raised/reduced by

Sensitivity Results

For graphical data analysis for sensitivity model runs, dot diagram and frequency distribution table are included. These plots are built with residual values computed as the difference between simulated hydraulic heads for test run and calibrated model. The dot diagram plots show the distribution of the average, minimum, maximum and standard deviation of the head difference for analyzed parameters, and for each monitoring well throughout the simulation. They summarize visually the spatial dispersivity of the sensitivity for analyzed parameters and identify outliers. The boxplots show the distribution of the average, minimum, maximum and standard deviation of the head difference for the analyed parameters, and for the entire model active zone.

Sensitivity results are grouped by urban and wetland areas. The histogram examines the frequency distribution of the mean daily residuals for observation wells, and for the entire model active cells with class marks of 0.5 ft. The dot diagram plots show the distribution of the average, minimum, maximum and standard deviation of the head difference for analyzed parameters, and for each monitoring well throughout the simulation. The boxplots summarize the median and the quartiles of the analized data.

Sensitivity Results for Observation Wells

Frequency distribution of mean heads residuals (simulation tested minus calibration) based on 197 wells is presented in table **18**. Tables **19** to **26** shows the effect of average, minimum, maximum and standard deviation head difference for each urban well and wetland in several parameters.

Table 18. Frequency Distribution of Mean Heads Residuals Based on 193 Wells

		CLASS OBSERVATION WELLS FREQUENCY					
Water Level Residual in feet	**Change**	**<-1**	**-0.75**	**-0.25**	**0.25**	**0.75**	**>1**
Stress and related variables							
	×1.5	9	11	166	7	0	0
ET maximum rate	×0.7	3	3	41	132	12	2
	+2 ft	0	0	8	184	0	1
ET surface elevation	-2 ft	2	0	189	2	0	0
	×2.0	7	1	179	6	0	0
ET extinction depth	×0.5	0	0	1	192	0	0
	×1.5	0	0	3	168	20	2
Recharge	×0.7	9	13	170	1	0	0
Aquifer parameters							
	×2.5	0	0	139	53	0	1
HK layer 1	×0.2	0	0	51	142	0	0
	×5.0	7	3	98	73	5	7
HK layers 2 and 3	×0.2	19	7	38	121	4	4
	×10.0	1	0	101	88	3	0
VCONT layer 1	×0.5	0	1	35	156	0	1
	×10.0	0	0	110	83	0	0
VCONT layer 2	×0.1	0	2	44	147	0	0
	+0.1	0	0	74	119	0	0
SY layer 1	-0.1	0	0	118	75	0	0
Surface-groundwater interaction							
	×1.5	3	3	41	132	12	2
Kadlec coefficient	×0.7	3	3	41	132	12	2
	+0.3 ft	0	0	52	141	0	0
SYWTL	–0.3 ft	0	0	135	58	0	0
	+0.3	0	0	54	139	0	0
SYMUC	-0.3	6	2	135	50	0	0
	×10	0	1	104	88	0	0
HKMUC	×0.1	4	4	107	62	12	4
Anisotropy factor in HKMUC	×20.0	0	0	140	53	0	0
	×0.02	0	0	38	147	5	3
	+2.0 ft	0	0	60	133	0	0
ZBOTT	-2.0 ft	0	0	131	62	0	0
	×100.0	3	0	112	78	0	0
GHB conductance	×0.01	0	2	44	133	11	3
	×5.0	0	1	103	86	3	0
River conductance	×0.1	6	3	61	111	10	2
	×5.0	4	3	148	38	0	0
Drain conductance	×0.1	0	0	170	23	0	0

Table 19. Effect of Average Head Difference for Each Wetland Well in Several Parameters.

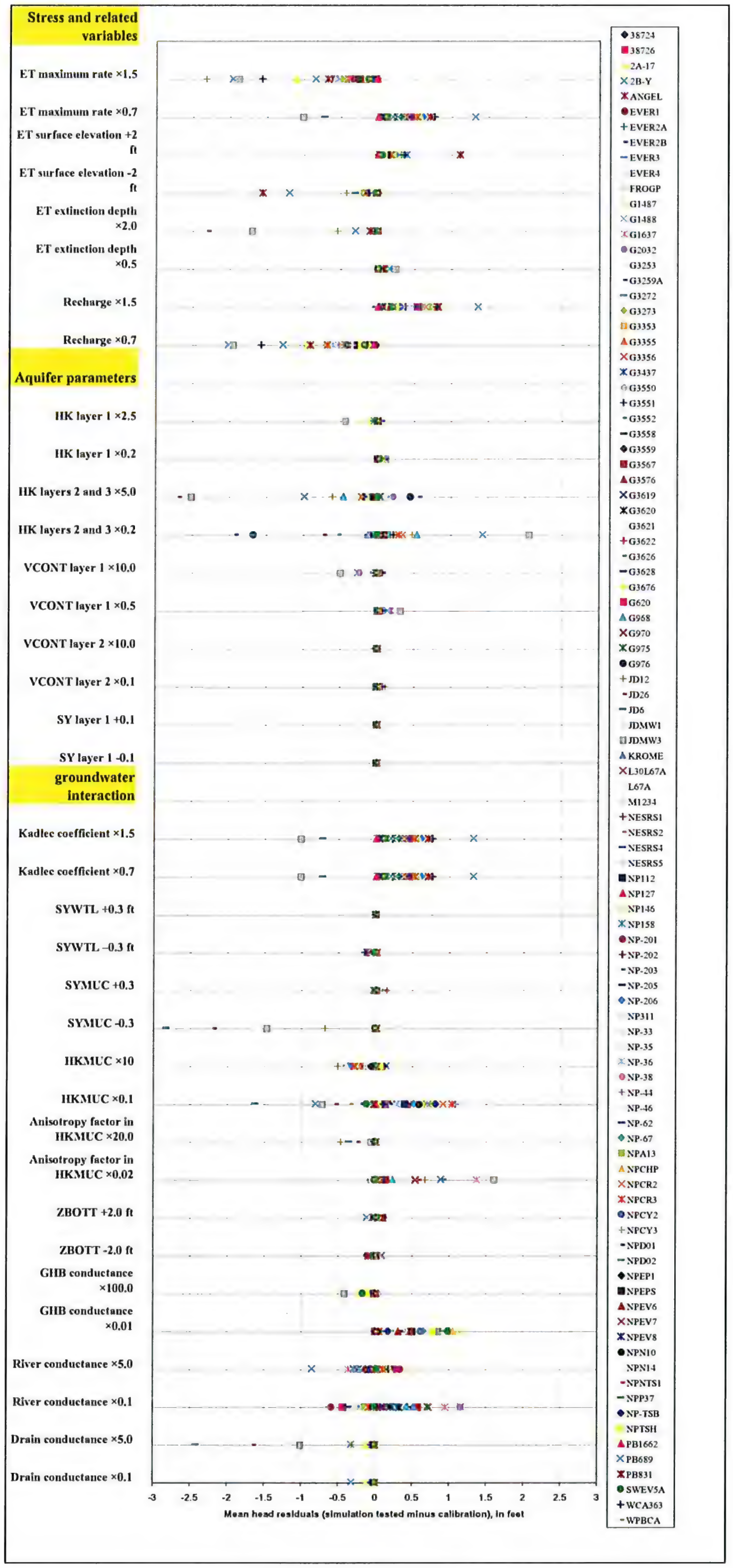


Table 20. Effect of Average Head Difference for Each Urban Well in Several Parameters.

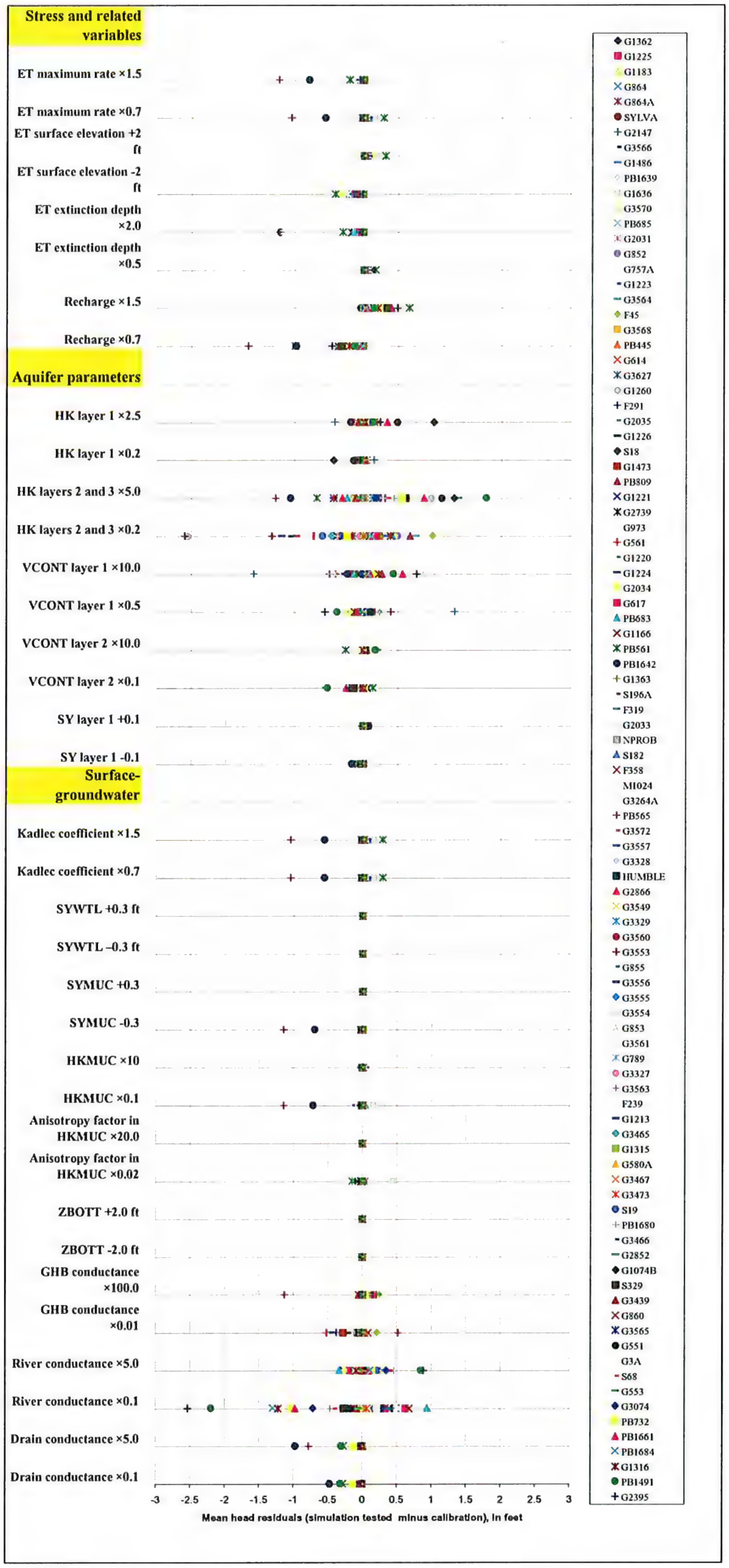


Table 21. Effect of Minimum Head Difference for Each Urban Well in Several Parameters.

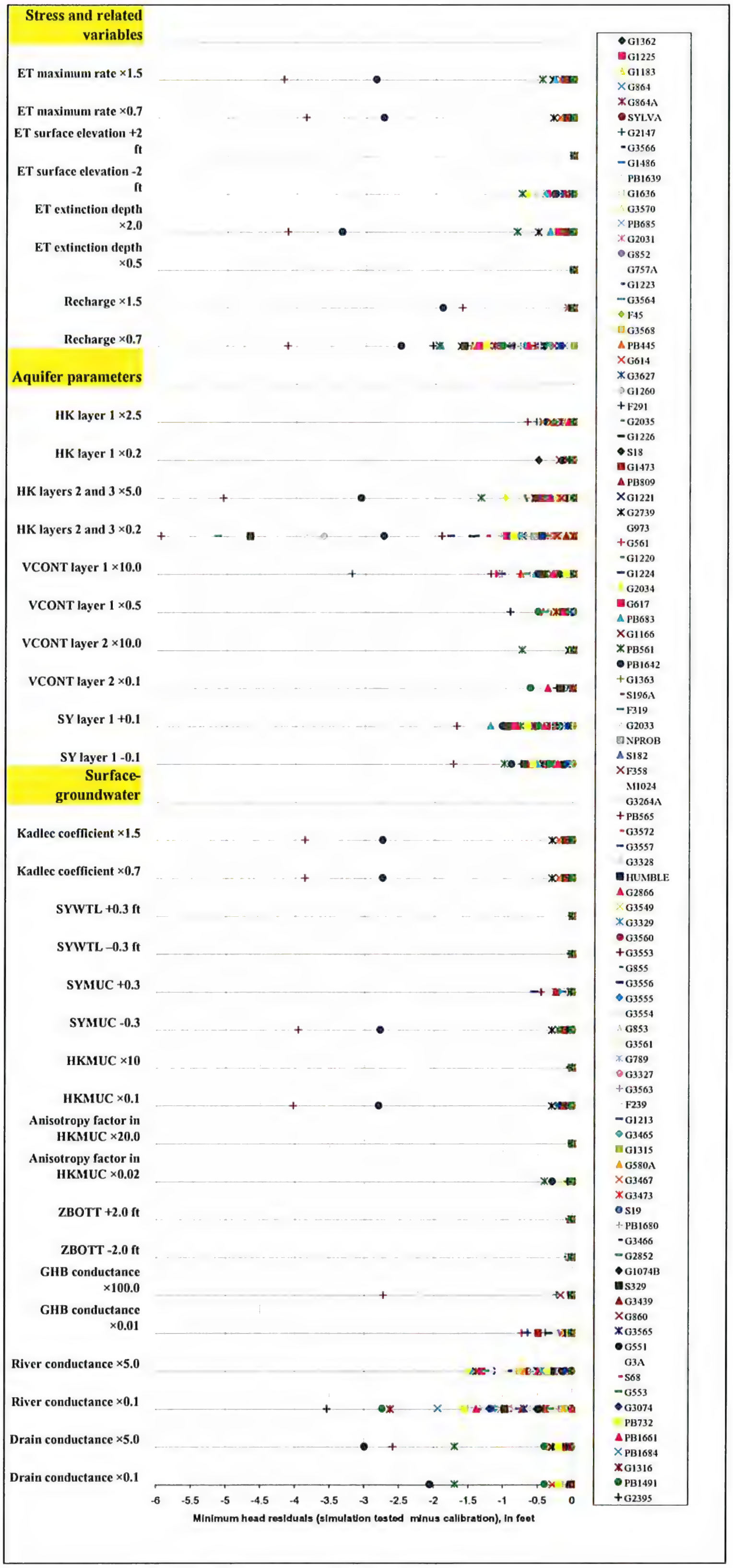


Table 22. Effect of Minimum Head Difference for Each Wetland Well in Several Parameters.

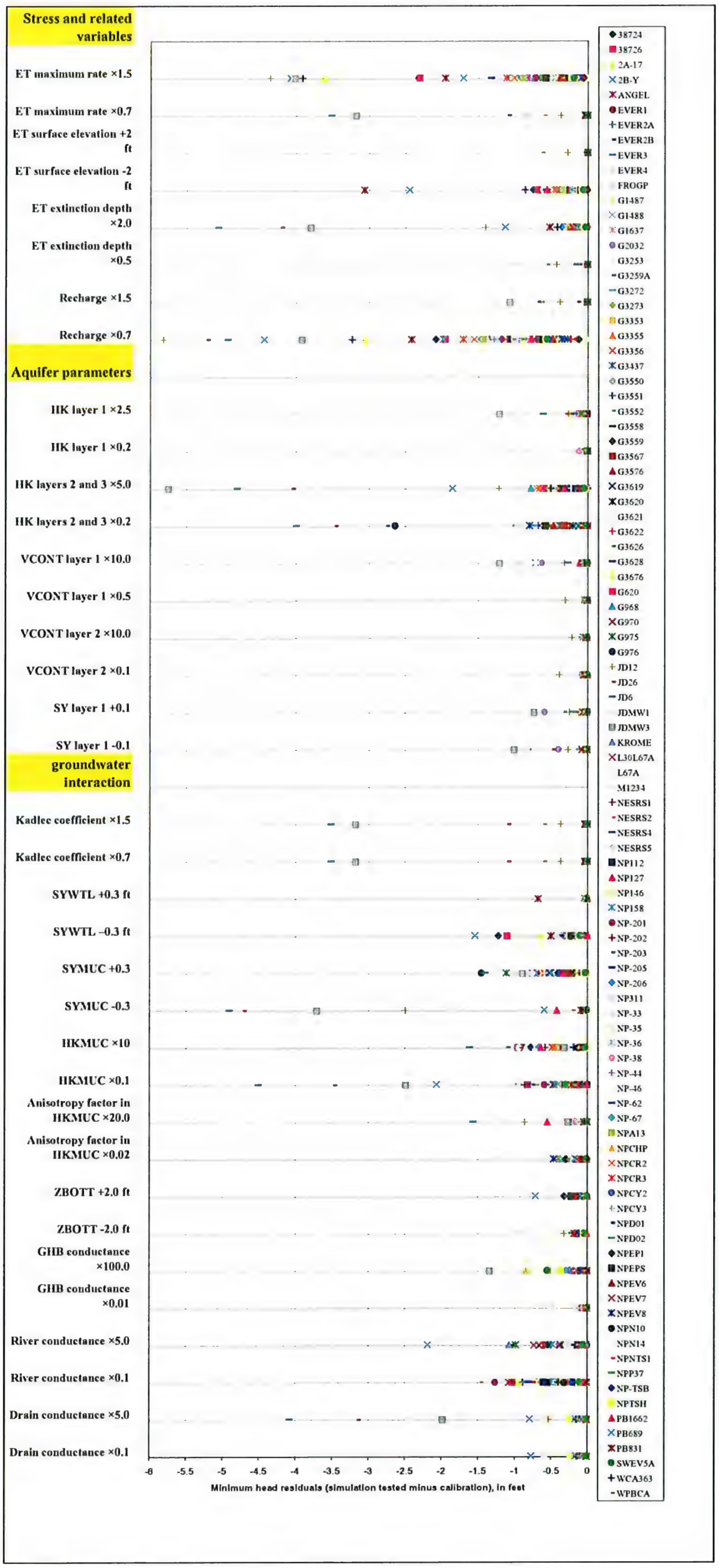


Table 23. Effect of Maximum Head Difference for Each Urban Well in Several Parameters.

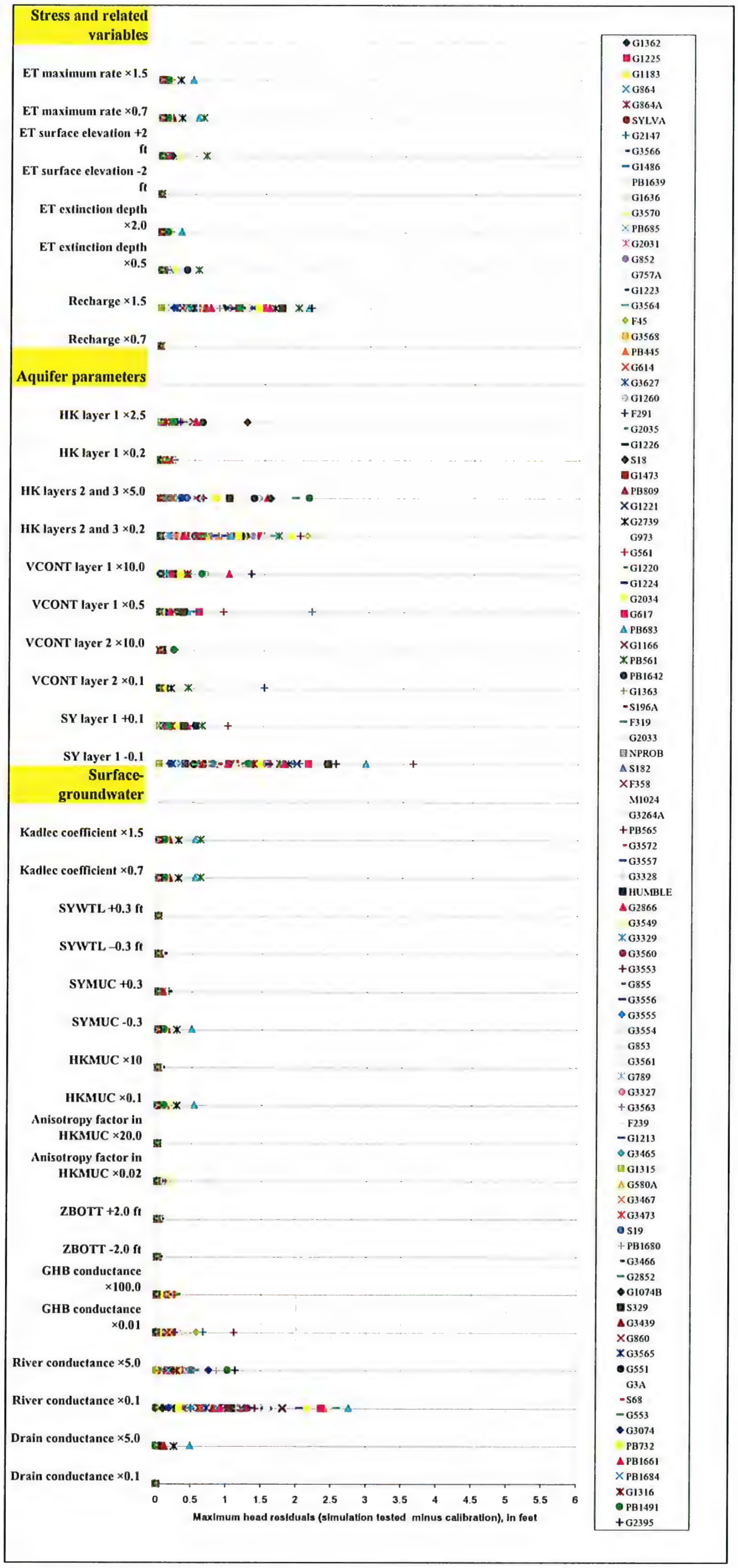


Table 24. Effect of Maximum Head Difference for Wetland Well in Several Parameters.

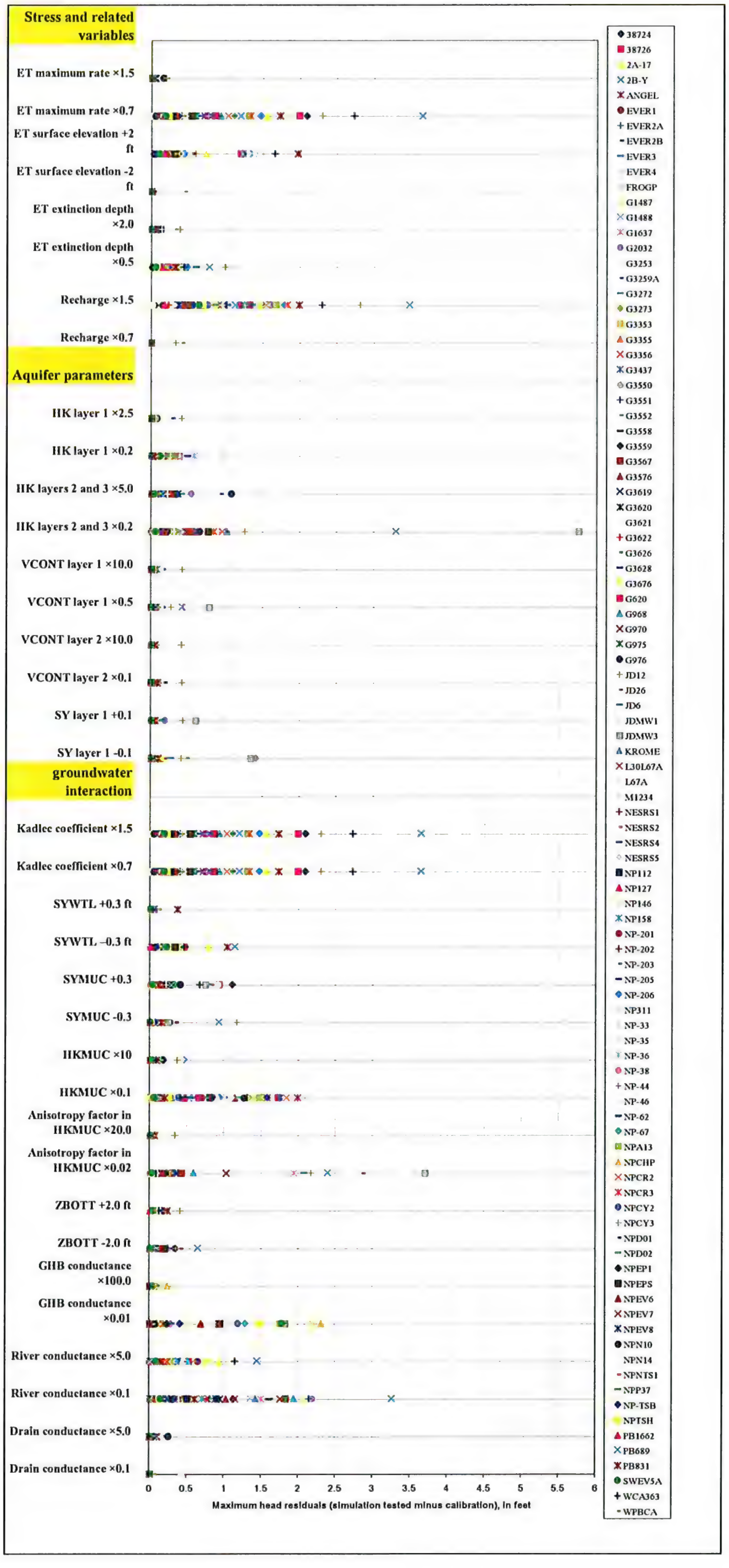


Table 25. Effect of Standard Deviation Head Difference for Each Urban Well in Several Parameters.

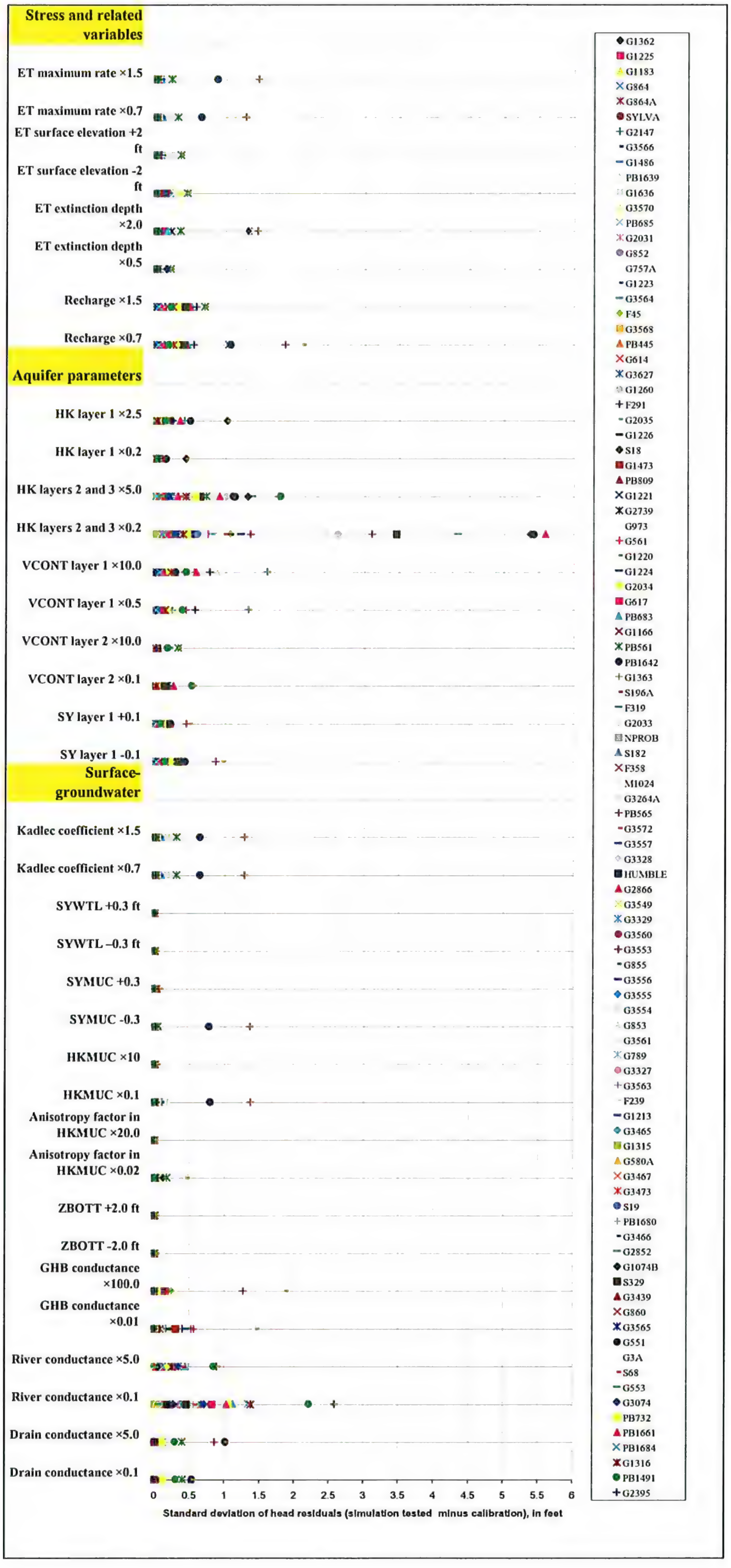
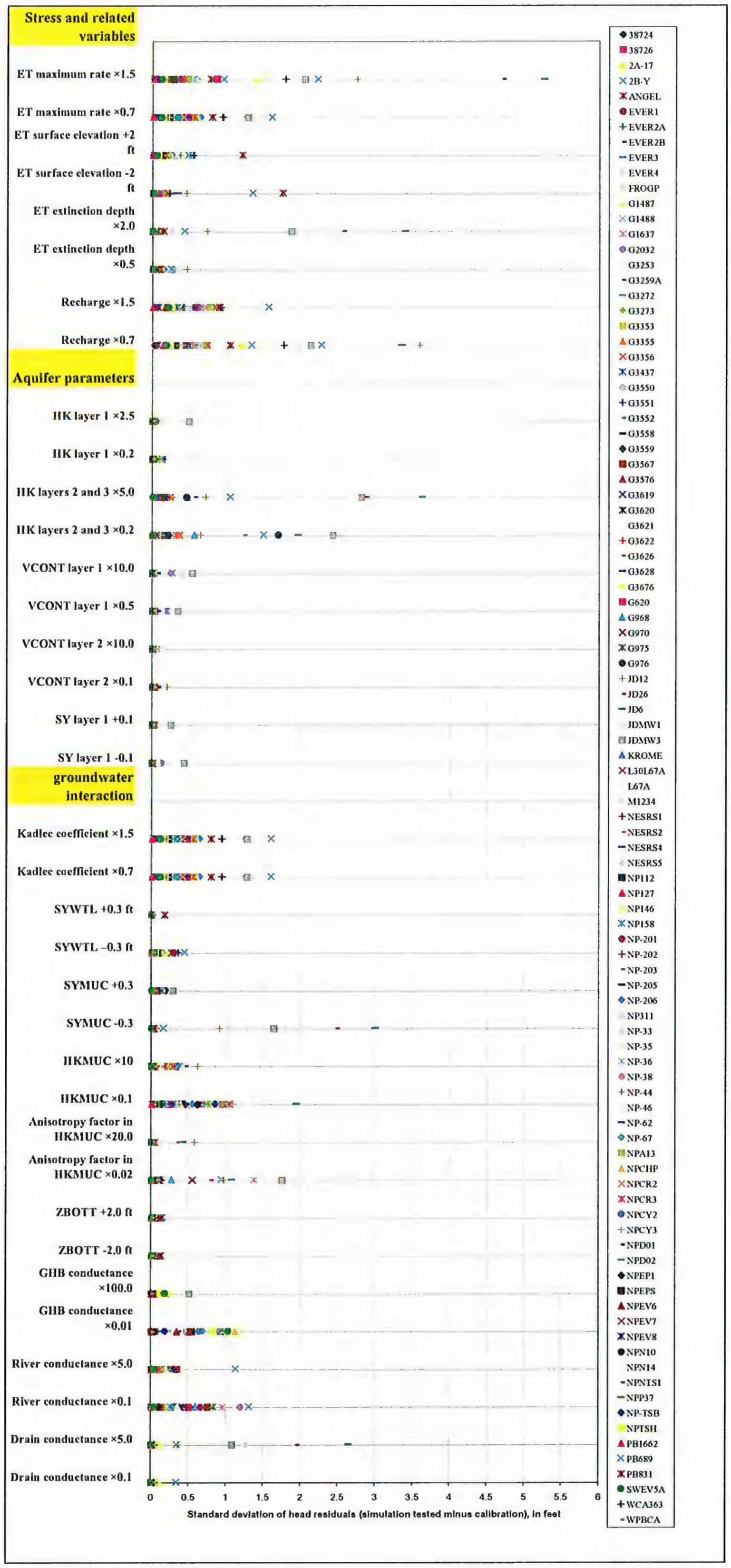


Table 26. Effect of Average Head Difference for Each Wetland Well in Several Parameters.



Stresses and Related Variables

ET maximum rate

The model is sensitive to increased ET for the urban and wetland environments (the range of mean residuals in -3 to 1.5 feet). The Wetlands areas are more sensitive to increases in the maximum ET rate. Gage 2B-Y in the wetland area is especially sensitive to variations in the rate with the mean residual values being reduced by up to 4 feet. Therefore the simulated water level values are lower than the calibration run when the rate is increased. Wetland wells are much more sensitive to changes in the maximum rate than non-wetland cells. Urban wells changed and average of between -1.5 to 0.5 ft from calibrated levels.

ET surface elevation

Decreasing ET Surface lowered the average mean residual by 0 to 1.5 ft, in wetlands. When the ET surface was increased the average residuals increased by an average of 0 to 1.0 ft.

ET extinction depth

Increasing extinction depth impacts the wetland wells more then the urban wells (an average maximum residual of -5 feet compared to -1). Decreasing the extinction depth, increased the mean residual by -0.5 foot for both urban and wetland wells As expected, when the extinction depth is deeper the water levels tend to drop, when it is shallower the water table increases.

Recharge

The model is sensitive to changes in recharge. When the recharge was increased the mean residual range for both Urban and Wetland area was between 0 to 1.5 ft. Frequency distribution table shows that the majority of the wells residual increased by 0.25 feet. When the recharge values decreased the impact was greater in the wetland wells with the mean residual ranging from -1 to -2.0 ft. (The negative residual indicate a decrease in the water levels in the wetlands when recharge is decreased). The model response to recharge in non wetland areas is moderate due to the influence of canals which tend to remove the water quickly due to the high hydraulic conductivity of the aquifer. Based on frequency distribution table, water levels tended to decline in many wells by reducing recharge and a clear skew exist towards reduced water levels by up to 2.0 foot. Only one well in urban areas was observed to increase significantly over calibrated values. This well is located near a drain. It is speculated that the drain is pulling the aquifer levels down under wet conditions but when reduces rainfall is applied the drain is off so it tends not to pull the water levels down. When recharge is increased, the exact opposite happens. Most wells show an increase in water levels. Frequency distribution table shows the skew towards increased water levels.

Aquifer Parameters

Horizontal hydraulic conductivity in layer 1 (aquifer)

The model appears to be not very sensitive to changes in the hydraulic conductivity of layer 1. This is a result of several factors. In the wetland areas, changes to the Block Centered Flow (BCF) package of modflow has no effect on the wetland areas because the wetland package over-writes the hydraulic conductivity values originally read in from the BCF package. In general, layer 1 has a significantly lower hydraulic conductivity and thickness than the underlying layer 2 which is the primary production zone for most of the model domain.

Horizontal hydraulic conductivity in layers 2 and 3

Layers 2 and 3 were modified together rather than separately. The model showed relatively greater sensitivity to these parameter in both wetland and non-wetland wells. When the hydraulic conductivity was increased the Urban areas responded greatly with the range of mean residuals is -8 to 3 ft (with most of the wells falling in the -1 to 1.5 foot range). In the wetland areas, the range is -4 to 4 ft, with most of the wells in the -0.5 to 0.5 foot range. When the hydraulic conductivity was decreased the mean residual in the wetland areas ranged from -3 to 2 ft. The residual range in the urban areas varies from -1 to 1 ft. For the majority of the wells, the mean residual decreased by 0.25 ft when the hydraulic conductivity was raised and went up 0.25 ft when it was lowered. The histogram shows a less skew distribution when the hydraulic conductivity was increased. When the values were decreased the pattern is skewed. Most of the wells (115) residuals increased by 0.25 a foot but 19 well residual decreased (water levels decreased) when the hydraulic conductivities were lowered. The model sensitivity to changes in this parameter was closely linked to recharge.

Vertical Conductance for Layer 1

As a whole, the model was fairly insensitive to the changes in vertical conductance (VCONT) values between layers 1 and 2. The model showed much greater differences in simulated heads in urban areas than wetland areas. Decreases in VCONT generally produced higher water levels in layer 1 wells, indicating a restriction in downward movement of groundwater, primary recharge from rainfall and canal leakance, from layer 1 to layer 2. An interesting exception occurs at well G853 in coastal Broward County. Decreasing the VCONT produced lower water levels than the calibration did, indicating restriction of upward flow from layer 2.

Vertical Conductance for Layer 2

Changes made to the VCONT values between layer 2 to layer 3 had very little overall effect on calibrated water levels in the observation points.

Specific Yield for Layer 1

The model is insensitive to changes in specific yield in the urban areas. Most of the wetland wells were not sensitive to changes in this parameter and mildly sensitive (changes of tenths of a foot) in the urban area. It should be noted that the specific yield for layer 1 is replaced by the specific yield specified in the wetlands package for the wetland areas. Therefore, in these sensitivity runs, the specific yield in the wetland areas is not modified. This increased sensitivity to specific yield during high recharge periods was also observed in most of the non-wetland wells. The model was far more sensitive to reducing the specific yield than increasing it. The minimum and maximum distribution dot diagram for decreasing the specific yield shows daily residuals for various wells indicating a change up to 4 ft at well PB-565.

Surface-groundwater Interaction

Kadlec coefficient

Non-wetland wells were insensitive to changes in this parameter. Wetland wells were only slightly sensitive to Kadlec coefficient changes. Sensitivity fluctuations in individual wells could not be definitively explained, and could be the result of a complex interaction with the operational packages (diversions and redirected flow). In well 2B-Y, a high sensitivity to decrease Kadlec is being affected by both recharge and by operational features, such as outflows from the reinjected drainflow package. Well 2B-Y is located in Water Conservation Area 2B which is the smallest of the WCA's and is bordered on two sides with urban seepage collection systems resulting in high gradients.

Specific yield in wetlands

The model responded with increased sensitivity to decreased specific yield values. The entire model was insensitive to the 1.0 value for specific yield of the surface water body.

Specific yield muck/aquifer underneath water body

Non-wetland wells were insensitive to changes in the muck specific yield. Wetland wells were more sensitive to decreasing the value than increasing, with differences in water levels from calibrated levels up to 2 ft. Sensitivity fluctuations in individual wells could not be definitively explained, and could be the result of a complex interaction of operational and other factors.

Horizontal hydraulic conductivity of the muck/aquifer underneath water body

The model's response to changes in this parameter varied. In general, non-wetland areas were insensitive to that parameter, with a few exceptions (e.g PB-1642)

when the parameter is lowered. These wells showed increased sensitivity (lower water levels) that closely correlated with periods of high recharge. The non-wetland wells were largely insensitive to the tenfold increase in muck conductivity.

The wetland wells were sensitive to changes in this parameter. The wetland wells located in the Everglades showed very similar sensitivity in both the decreased run and increase run, in both magnitude and direction of change from calibrated values. This is because the calibrated muck conductivity values are extremely high in those areas. Wetland wells did show a pattern of increased sensitivity during different times, but it was not as closely related to recharge as was seen in the non-wetland wells. Increase sensitivity to muck conductivity in modeled wetlands is due to water surface fluctuations (non-pounded areas) probably also influenced by water management operations.

General head boundary conductance

Sensitivity to this parameter was negligible except for areas very close to boundaries. The test runs showed more sensitivity when boundary conductance was decreased than when it was increased.

River conductance

The model is sensitive to changes in the river and drain conductance, with the Urban areas being more sensitive to increased in conductance. The mean residual range in the Urban area is -0.5 to 1.0 ft. The majority of mean residual values by increasing value were between -0.5 and 0.5 feet. The model was sensitive to reduction in river conductance but began to experience convergence issues in some areas when the conductance was increased. This is not unexpected, considering the abundance of canals and drains in the LEC and the high hydraulic conductivity of subsurface materials. When the canal conductance is decrease by a factor of 0.1, the frequency distribution table shows a slight bias to higher water levels which would be expected. The numerous canals that have been constructed in south Florida where built primarily to drain the land. So by limiting the canals ability to remove water, it would tend to increase water levels when conductance values where lowered.

Many of the observation wells showed increased sensitivity to changes in river conductance during periods of high recharge. Some wells would respond with higher water levels during high recharge when the conductances were lowered, because the nearby canals were less able to get rid of the water. Conversely, those wells had lower water levels than the calibrated run when conductances were high, because the nearby canals lost more water through the open connection to the aquifer. In other wells such as JD12 or 2B-Y, the sensitivity to river conductance was more complex, being affected by both recharge and by operational features, such as outflows from the reinjected drainflow package. Well 2B-Y is also located in Water Conservation Area 2B which is the smallest of the WCA's and is bordered on two sides with urban seepage collection systems resulting in high gradients. It should be noted that instability was observed in the major wetland systems when the conductance was increased. Care should be taken when

increasing the conductance values for the perimeter canal systems that surround these systems.

CHAPTER 5
Conclusions and Future Improvements

MODEL LIMITATIONS

A model is any device that represents an approximation of a field situation (Anderson and Woessner 1992). The model described in this report is a numerical groundwater flow model with coupled surface/groundwater flow in the wetlands area utilizing the well known computer code MODFLOW to approximate, on a subregional scale, the groundwater flow system within the Surficial aquifer system in southeast Florida.

The Lower East Coast Subregional flow model developed in this report is based upon a simplified representation of the complex heterogeneous groundwater flow system. The governing equation utilized to solve the flow system is the continuity equation derived from the principle of mass balance incorporating Darcy's Law. This equation assumes that the flow in laminar and does not reach turbulent conditions which is general true throughout the study area, for the groundwater system, with the possible exception of flow near some major production wells in the Biscayne aquifer. The horizontal and vertical discretization of the model assumes that the hydraulic properties are the same throughout the cell which a simplification of the aquifer properties considering the size and thickness of each grid cell.

The spatial distribution of evapotranspiration and recharge is dependent upon 11 and 26 stations respectively. Considering the sporadic nature of rainfall in south Florida some error may be introduced because the data sets do not necessary represent actual rainfall patterns. Recent advancements in meteorology, including the widespread use of Doppler radar should help in better refining rainfall patterns over a large area. However, this type of data is presently not available for simulations of conditions that occurred 20 years ago. In addition the historical data from the monitoring sites has data gaps that must be filled from adjacent stations which introduce additional error to the model.

The lack of water level data, especially in Martin and Palm Beach Counties introduces uncertainty into the model in certain areas. There is a complete lack of any available monitoring data throughout the Everglades Agricultural Area. There is only sporadic data available for northern Palm Beach and Martin Counties. Central and southeastern Palm Beach Counties are not as problematic due to the highly managed secondary canal systems. The actual water level data itself was in generally good condition with no significant problems detected. Some of the flow data from the structures appear to have some issues which may introduce some additional errors.

The simulation of flow through the C-18 canal utilizing the diversion package is a simplified method and can not be used for canal sizing or routing capabilities. This method was utilized to see if long term simulations could reasonably predict structure flows in a computationally efficient manner. Similarly, the redirected flow package and the diversion package utilized to move water through the Water Conservation Areas should include additional features to improve the routing of water through the system.

The topography utilized in the model development was in a constant state of updating, modifying, adding, changing and general disarray. Errors associated with the topography primarily impact to the areas covered by the wetland systems in the model.

The model is designed to be handle regional and basin level projects. Projects utilizing the model for local areas such as a wellfield should consider a partial recalibration of the model at the site specific location with a detailed collection of all historical data available, especially wellfield and individual well daily pumpage rates. The size of the grid should also be taken into consideration when evaluating local projects.

In spite of the limitations, the model can provide an understanding of the movement of water in the study area. The model proved quite robust considering the long term daily calibration and verification periods in its overall performance during the simulation period. The calibration period included both a 1 in 100 year drought and a 1 in 100 year wet events and the model did not react adversely to these extreme events. The LECsR model conceptualization and discretization was designed at a subregional or basin level scale. The special variability of the input parameters is also best described at a similar scale. Therefore, the model should be used for regional to subregional or basin level projects and interpretation of the results should also be at that scale. The hydraulic parameters utilized in the model can be used as initial estimates for more localized models. In addition, the model does provide a reasonable estimate of drawdowns associated with wellfield withdrawals and the ground/surface water interactions within wetland systems.

CONCLUSIONS

The Lower East Coast of Florida includes all or portions of southern Martin, Palm Beach, Broward, Miami-Dade, mainland Monroe and eastern Collier and Hendry Counties. The Surficial aquifer system is the principle aquifer in the region and includes the extremely prolific Biscayne aquifer with yields in excess of 7,000,000 gallons per day per foot of drawdown. This area also includes approximately 50 percent wetland systems including the world renowned Everglades system and the Everglades National Park. Also included in the region is the vast sugar cane fields of the Everglades Agricultural Area and the sprawling urban areas along the coast. A three dimensional numerical groundwater flow model with coupled surface-groundwater in the wetland areas was developed using the USGS code MODFLOW with additional packages to simulate conditions unique to south Florida. The model was developed by combining and

updating previous county level models which simulated coastal conditions and expanding the overall extent of these models to include the majority of the lower east coast of Florida. The overall active model domain is approximately 7,500 square miles.

The sediments composing the Surficial aquifer system and the Biscayne aquifer are primary marine carbonate and clastic sediments of Pleistocene to Miocene age. The model was discretized into three layers utilizing Chronostratigraphic correlation of the sub-aerial exposure surfaces within these sediments resulting from the periodic submergence and emergence of the Floridan peninsula from fluctuations in sea level stands. A grid spacing of 704 foot by 704 foot was chosen to match the SFWMD regional models which can be used to provide internal boundary conditions for future simulations. The model was calibrated over an extend period of 14 years from January 1986 through September of 1999 with daily time steps and stress periods. The model was primarily calibrated to observed heads with an overall mean error of 0.0 feet, a mean absolute error of 0.54 feet and root mean square error of 0.72 feet. The calibration results indicate a reasonable match between observed and measured water levels in most areas of the model domain. The model was verified from September, 1999 through December, 2000 and produced similar results to the calibration period. The budget from the model indicates that recharge to the aquifer is the primary inflow to the system with evapotranspiration and canal drainage as the primary outflows.

A sensitivity analysis was conducted in which 36 individual variables were analyzed where the values were increased and decreased within a predefined range of known values. The results were analyzed utilizing the mean head residuals, the maximum head residuals, the minimum head residuals and the standard deviation of the head residuals. The results were also evaluated separately for the developed and wetland areas. The results for the developed areas indicate that increases and decreases in the hydraulic conductivity of layers two and three and decreases in the river conductance were the most sensitive. In addition to these three parameters, noticeable individual wells showed biased sensitivity to changes to specific yield in layer one and the amount of recharge applied to the urban areas. The wetland systems were significantly more sensitive to changes in parameter values with noticeable changes to wetland stages when changes were made to all ET parameters, recharge, changes to the Kadlec number, the hydraulic conductivity of layer one underlying the wetland systems, changes to the hydraulic conductivity of layers two and three, the general head boundary and changes to the river conductance values.

Some conclusions and recommendations from the model development effort are as follows:

- Although the model covers a large area, the grid resolution is such that it can be used for both a basin level to regional analysis.
- Use of the model at a local scale requires additional data collection and partial recalibration of the model prior to its use at a wellfield level. Depending upon the project, a finer grid size may also be necessary.

- The creation of a single model, as opposed to six county level models is easier to maintain, easier to simulate single or multiple projects, and ensures a consistent methodology for developing input data sets.
- The model reasonably simulates the groundwater/surface water interactions in the wetland systems. Some potential improvements include the addition of a dual porosity component to increase overland flow in a preferential pathway and the modification of the wetlands code to include Manning's roughness coefficients.
- An unsaturated zone package similar to that developed by FAU (2001) and Geotrans (2004) should be included in future model refinement to eliminate the cumbersome pre-processing for the evapotranspiration and recharge packages.
- The model requires extensive amounts of storage when ran for 15 – 40 years on a daily stress period. Storage space needs to be made available prior to running any long term simulations.
- The sensitivity of the model should include all active cells within the model domain and not just the selected observation nodes. This should significantly increase the sample size to provide a more statistically robust analysis of model sensitivity.
- The model utilized saw grass as the reference crop in developing the potential evapotranspiration to be consistent with the SFWMD regional model. This approach is not consistent with the Water Use Permitting section of the District which utilizes grass as the reference crop. The potential evapotranspiration should be recalculated with grass as the reference crop.
- The topography for the model comes from a myriad of different sources and methods of data collection. A uniform standard for collection and development of the topography needs to be implemented.
- The model was developed utilizing MODFLOW 96. The various packages should be rewritten in Fortran 90 for inclusion in MODFLOW 2000/SEAWAT. The use of SEAWAT would allow for the simulation of the saline interface and improve calibration in the coastal observation wells. Several studies have been undertaken utilizing SEAWAT in Miami-Dade and Broward counties which could help in implementing the density dependent conditions.
- The use of the diversions package for simulating a simplified structure flow routine should be implemented elsewhere in the model. This should help provide a better mass balance of the overall water budget of the study area.
- Develop an artificial "average" and "1 in 10 year drought" rainfall and evapotranspiration data sets to assist Water Use Permitting in regulatory issues.

- Conditional stochastic simulation such as sequential Gaussian simulations should be investigated for the distribution of point data, such as the hydraulic conductivity, to help eliminate the "bulls eye" effect of standard inverse distance weighing technique utilized in the development of the input data sets.

Implementing several of the above recommendations could improve the models performance in several areas. However, the model in its existing condition does provide a good understanding of the flow system and can be used to evaluate water management scenarios.

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APPENDIX A
Hydrologic and Hydrologic Data

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Table 27. LECsR Biscayne or Surficial Aquifer Performance Test Results

	Well Location[a]			
Well Name	**X**	**Y**	**HK[b] (ft/day)**	**Thickness (ft)**
DADE-52	944824	566710	6357	40
DADE-53	924256	569405	5000	50
DADE-54	903062	570691	6750	40
DADE-51	924256	569405	10000	40
DADE-61	912358	589223	5500	50
DADE-63	901469	593803	2600	50
DADE-CC	802783	600824	6000	40
HIGH-04	958794	756061	1250	50
PB-1574	916970	759977	480	64
Morikam	932971	759977	1300	50
PB-1581	927970	739977	925	95
NSID	885970	709977	100	50
G1260	945912	722211	200	50
G1213	922626	713008	300	50
G1315	934080	710491	10	50
G2147	950443	697779	20000	50
G1316	922626	695513	250	50
G1215	946815	708363	2500	50
G820A	930721	678308	250	50
PB491	952750	735464	1250	50
PB1455	946922	735340	400	50
PB1457	957657	747485	1250	50
PB1158	957657	754696	1250	50
McCart	819085	1058463	33	40
Allap	824356	1002412	58	60
cauk	860786	997062	50	120
jdsp	945537	973063	150	160
jup	939904	943310	100	165
pb15	906536	945312	35	76
pbpc	892636	935362	36	55
teq	952737	959763	250	220
fpl2	808494	977251	53	45
jdsp	928086	979688	100	90
mobil	907136	1003863	80	53
monrv	884286	939663	56	60
mapwd	941987	939363	58	90

Well Name	Well Location[a] X	Y	HK[b] (ft/day)	Thickness (ft)
jonl	951537	939663	91	110
mecca	943837	930362	57	100
hobe4	937986	988363	126	180
hobe5	937136	989063	76	140
acme	910909	829724	130	20
palms	940419	841728	3800	45
boyn	940801	798815	1600	70
sys3	936822	782632	2000	80
lant	949266	852089	1300	50
sshor	903754	842403	40	40
pb1598	927408	776815	380	84
pb1603	948839	805434	310	64
pb1578	954014	831220	560	14
pb1571	926587	819624	3200	45
pb1544	926983	842649	2800	75
pb1576	909055	805822	1300	27
i95	950360	898648	14	40
hood	940246	919985	1000	40
wpb	942435	878397	1000	40
jup	939904	943310	70	40
riv	947545	886611	2000	40
pb1567	892975	854962	70	40
pb1564	899423	884686	60	40
pb1558	876043	900610	50	40
pb1555	912643	901730	1250	40
pb1550	887449	918848	40	40
pb1607	924443	926544	100	40
lakel	949266	852089	600	80
stlucie	885536	1004613	32	84
banyan	900636	1022013	42	95
MilesG	922236	1022413	52	115
Hydra	932086	1005463	49	150
Hobe	936086	996363	50	40
Vista	917636	1015763	33	100
C23	797236	1044063	45	80
L65	770636	1008762	53	70
MDown	878086	1036513	100	120
LFarm	879523	1018913	78	60
Stuso	905486	1029513	40	100
Woods	890086	1041613	33	120
Piper	893586	1023663	59	90

	Well Location[a]			
Well Name	**X**	**Y**	**HK[b] (ft/day)**	**Thickness (ft)**
GDC	872536	1039463	62	65
HR2	882986	1045563	97	83
SR76	901536	1028163	33	100
Stuart	902668	1038900	33	100
FPL1	808590	991248	53	35
FPL3	799882	995669	48	70

a. Location in Florida East State Plane coordinates, NAD 1983 Datum.

b. Horizontal Hydraulic Conductivity.

Table 28. Aquifer Performance Test Results Based on Specific Capacity Well Measurements

Permit No.	Well Location[a] X	Y	Casing Depth (ft)	Total Depth (ft)	HK[b] (ft/day)
50-00367-W	944308	691738	110	162	2462
50-00367-W	936714	749858	110	162	329
50-00367-W	941056	749896	110	162	1469
50-00367-W	943104	749595	110	162	470
50-00367-W	941076	749019	110	162	529
50-00367-W	941101	756910	110	162	1361
50-00367-W	941114	745522	110	162	1069
50-00367-W	898364	713324	110	162	100
50-00367-W	928988	721526	110	162	250
50-00367-W	946842	721909	110	162	1000
50-00367-W	949338	719874	110	162	2111
50-00367-W	942220	717652	110	162	1000
50-00367-W	947000	713129	110	162	857
50-00367-W	948388	712812	110	162	700
50-00367-W	946280	700747	110	162	4400
50-00367-W	945533	698272	110	162	6364
50-00367-W	945287	695323	110	162	5500
50-00367-W	928988	702850	110	162	250
50-00367-W	904937	706711	110	162	100
50-00367-W	898647	695123	110	162	292
50-00367-W	913388	694080	110	162	3800
50-00367-W	911824	685101	110	162	783
50-00367-W	899306	679203	110	162	360
50-00367-W	917423	678234	110	162	1000
50-00367-W	918650	679956	110	162	1000
50-00367-W	919745	677628	110	162	1000
50-00367-W	923041	677742	110	162	1000
50-00367-W	898096	669198	110	162	1600
50-00367-W	916644	668756	110	162	4875
50-00367-W	912936	661994	110	162	4875
50-00367-W	879958	648924	110	162	2500
50-00367-W	895432	650594	110	162	4000
50-00367-W	908903	653490	110	162	4700
50-00367-W	916142	647639	110	162	1069
50-00367-W	916529	642859	110	162	1069
50-00367-W	908266	633445	110	162	7333

Permit No.	Well Location[a] X	Y	Casing Depth (ft)	Total Depth (ft)	HK[b] (ft/day)
50-00367-W	868318	622154	110	162	2000
50-00367-W	884253	627801	110	162	27500
50-00367-W	895039	626652	110	162	1069
50-00367-W	934547	624071	110	162	9500
50-00367-W	934607	623449	110	162	7368
06-00135-W	903691	611839	110	162	15000
50-00367-W	912426	588974	110	162	6000
50-00367-W	924784	597283	110	162	3421
50-00367-W	924310	609601	110	162	25000
50-00367-W	925553	612734	110	162	40000
50-00367-W	931353	604036	110	162	50000
50-00367-W	933371	603026	110	162	7368
50-00367-W	858214	609072	110	162	2000
50-00367-W	846787	617773	110	162	200
50-00367-W	844059	653896	110	162	1633
50-00367-W	902761	581776	110	162	6750
50-00367-W	848884	553090	110	162	50000
50-00367-W	849604	548258	110	162	50000
50-00367-W	847753	545071	110	162	50000
50-00367-W	888161	543734	110	162	10000
50-00367-W	889600	538901	110	162	5000
50-00367-W	891040	544865	110	162	10000
50-00367-W	855465	494279	110	162	45000
50-00367-W	866980	496643	110	162	15000
50-00367-W	848833	421895	110	162	5000
50-00367-W	826521	416446	110	162	8000
control	936500	653743	110	162	12000
control	821228	401306	110	162	75000
control	844662	394158	110	162	75000
control	821680	385110	110	162	25000
control	824396	384985	110	162	25000
control	818748	385205	110	162	25000
control	821815	381338	110	162	25000
control	947287	707342	110	162	125
control	946497	707440	110	162	125
control	946991	708249	110	162	125
control	945442	707440	110	162	125
control	945422	708378	110	162	125
control	945659	706720	110	162	125
control	946478	706602	110	162	125
control	947316	706611	110	162	125

Permit No.	Well Location[a] X	Y	Casing Depth (ft)	Total Depth (ft)	HK[b] (ft/day)
50-00367-W	826110	407192	110	162	75000
control	821806	391748	110	162	75000
control	814573	388630	110	162	75000
control	948254	708491	110	162	125
control	948496	707744	110	162	125
control	949462	707414	110	162	125
control	949462	707414	110	162	125
control	948408	707129	110	162	125
calib	903691	611839	110	162	15000
calib	866980	496643	110	162	5000
calib	946280	700747	110	162	4400

a. Location in Florida East State Plane coordinates, NAD 1983 Datum.

b. Horizontal Hydraulic Conductivity.

Table 29. Summary Table of USGS Geologic Core Data Used in LECsR Model

Well	X^h	Y^h		Ground Elevation (NGVD)	Holocene	Q5	Q4	Q3	Q2	Q1	T1	T2	T3	Source
PB-1428	886287	734567	Thickness (ft)	11	3	3	10	30	20	14	53	20	40	a,c
			Litho	11	3	5	4	5	5	5	7	5	7	
			HK (ft/day)	11	25	250	50	10	50	200	100	100	20	
G-2342	916671	690216	Thickness (ft)	13	3	10	23	23	44	30	43	40	80	a,c
			Litho	13	1	5	1	1	3	5	5	5	1	
			HK (ft/day)	13	25	25	10	25	50	1000	250	75	50	
G-2323	916909	725556	Thickness (ft)	12	3	13	22	21	56	20	10	24	90	a,c
			Litho	12	1	7	1	1	3	3	7	7	7	
			HK (ft/day)	12	25	25	20	50	100	1000	50	1000	20	
G-2325	940840	725711	Thickness (ft)	14	4	21	48	3	37	40	25	25	95	a,c
			Litho	14	1	1	1	1	1	5	1	1	7	
			HK (ft/day)	14	25	25	25	25	750	250	100	200	50	
G-2344	944423	693929	Thickness (ft)	16	3	20	26	17	60	20	38	33	175	a,c
			Litho	16	1	1	1	7	3	5	7	3	7	
			HK (ft/day)	16	25	25	20	500	5000	50	250	750	50	
G-2345	915567	647095	Thickness (ft)	13	2	14	13	29	38	17	30	48	130	a,c
			Litho	13	1	1	1	1	5	5	5	7	1	
			HK (ft/day)	13	25	25	20	25	500	500	200	1000	50	
G-2322	895800	644557	Thickness (ft)	13	6	8	20	27	33	10	50	50	14	a,c
			Litho	13	1	1	1	7	7	5	7	7	1	
			HK (ft/day)	13	25	50	50	50	13000	13000	500	20	5	

Well	X^h	Y^h		Ground Elevation (NGVD)	Holocene	Q5	Q4	Q3	Q2	Q1	T1	T2	T3	Source
G-2321	864034	652972	Thickness (ft)	6	3	6	10	32	12	10	70	30	50	a,c
			Thickness (ft)	6	3	6	10	32	12	10	70	30	50	
			HK (ft/day)	6	25	50	5	250	750	24000	5	25	1	
G-2319	827644	658970	Thickness (ft)	8	3	3	7	8	15	10	64	43	53	a,c
			Litho	8	2	5	1	1	5	5	7	5	7	
			HK (ft/day)	8	25	50	5	5	750	23000	5	590	5	
G-2320	789096	655135	Thickness (ft)	8	2	3	7	9	11	10	38	81	41	
			Litho	8	2	5	5	7	5	5	7	5	7	
			HK (ft/day)	8	25	5	500	5	250	2600	50	910	5	
G-2327	903730	597350	Thickness (ft)	6	3	7	14	25	64	10	23	30	96	a,c
			Litho	6	1	1	1	1	5	5	5	1	1	
			HK (ft/day)	6	25	50	50	50	50	35000	250	50	50	
G-2318	872004	590616	Thickness (ft)	6	3	6	11	23	30	16	20	30	64	a,c
			Litho	6	2	1	1	5	5	7	7	5	1	
			HK (ft/day)	6	25	50	50	750	750	17000	1000	5	5	
G-2317	848365	590302	Thickness (ft)	7	2	3	6	20	20	24	16	40	80	a,c
			Litho	7	2	5	5	5	5	5	5	5	9	
			HK (ft/day)	7	25	50	50	2500	2500	34000	5	1	1	
G-2341	885894	689533	Thickness (ft)	12	6	3	10	30	37	20	13	17	43	a,c
			Litho	12	1	5	5	3	7	5	1	1	1	
			HK (ft/day)	12	25	5	50	50	50	50	50	250	5	
G-2312	833166	689685	Thickness (ft)	7	3	3	7	13	10	3	66	46	70	a,c
			Litho	7	2	5	5	5	1	5	7	1	7	
			HK (ft/day)	7	25	5	5	50	5	5	50	650	5	
G-2347	935594	637731	Thickness (ft)	6	4	13	20	27	40	23	20	59	130	a,c
			Litho	6	1	8	1	7	6	3	5	3	7	
			HK (ft/day)	6	25	50	50	10000	10000	10000	1000	500	250	
G-2315	796254	727005	Thickness (ft)	14	4	4	16	10	6	8	63	43	80	a,c

Well	X^h	Y^h		Ground Elevation (NGVD)	Holocene	Q5	Q4	Q3	Q2	Q1	T1	T2	T3	Source
			Litho	14	2	5	5	5	5	5	7	5	7	
			HK (ft/day)	14	25	1	50	50	50	50	5	500	20	
G-2316	804459	591138	Thickness (ft)	7	3	4	6	20	7	19	33	67	37	a,c
			Litho	7	2	5	5	5	5	5	1	5	5	
			HK (ft/day)	7	25	5	5	20000	20000	20000	1	500	5	
G-2328	933816	602481	Thickness (ft)	10	9	17	20	34	40	14	30	43	77	a,c
			Litho	10	1	5	3	6	3	3	3	3	5	
			HK (ft/day)	10	50	50	500	30000	30000	30000	250	50	50	
G-2311	838895	627921	Thickness (ft)	7	5	4	10	14	35	7	30	38	41	a,c
			Litho	7	1	5	5	1	5	5	7	5	7	
			HK (ft/day)	7	25	50	20	11000	11500	500	5	5	5	
G-3300	924151	556986	Thickness (ft)	14	1	15	20	34	27	20	50	33	20	b,d
			Litho	14	1	7	4	3	7	5	7	3	5	
			HK (ft/day)	14	25	20	200	5800	500	500	750	750	50	
G-2610	945682	618688	Thickness (ft)	5	10	27	25	16	32	20	70	50	50	
			Litho	5	9	5	3	5	3	5	5	5	5	
			HK (ft/day)	5	5	50	50	25000	25000	25000	50	500	250	
G-3472	944594	587407	Thickness (ft)	10	10	10	25	30	35	10	50	33	20	
			Litho	10	1	6	5	6	5	5	7	3	5	
			HK (ft/day)	10	25	20	100	6400	6400	50	750	750	50	
G-3299	894693	548130	Thickness (ft)	8	4	8	23	19	40	13	43	27	43	b,d
			Litho	8	1	8	1	5	3	3	1	5	1	
			HK (ft/day)	8	25	7600	50	7600	7600	7600	500	200	20	
G-3298	858148	547742	Thickness (ft)	9	2	10	14	12	20	10	70	24	16	b,d
			Litho	9	2	8	5	5	7	5	7	7	1	
			HK (ft/day)	9	25	20000	20000	20000	20000	20000	200	500	1	
G-3296	776342	559956	Thickness (ft)	7	5	4	6	8	6	10	38	98	20	b,d
			Litho	7	2	5	5	5	5	5	7	7	1	

Well	X^h	Y^h		Ground Elevation (NGVD)	Holocene	Q5	Q4	Q3	Q2	Q1	T1	T2	T3	Source
			HK (ft/day)	7	25	5	40000	40000	40000	40000	50	500	1	
G-3297	825881	551440	Thickness (ft)	8	4	6	9	12	10	15	62	32	20	b,d
			Litho	8	5	8	5	5	5	5	7	7	1	
			HK (ft/day)	8	5	50	29000	29000	29000	29000	50	200	1	
PB-690	960982	771693	Thickness (ft)	11	5	10	25	25	52	28	30	30	70	g
			Litho	11	1	1	5	5	5	4	1	1	1	
			HK (ft/day)	11	25	50	50	50	570	50	10	10	10	
PB-1108	906014	752248	Thickness (ft)	14	4	11	22	38	20	10	19	31	20	g
			Litho	14	2	5	1	4	5	5	1	4	1	
			HK (ft/day)	14	25	50	50	50	500	500	10	5	5	
PB-1103	927565	752381	Thickness (ft)	21	5	10	15	56	34	20	20	20	40	g
			Litho	21	1	1	1	1	5	5	5	5	5	
			HK (ft/day)	21	25	50	50	50	1600	1600	1600	50	10	
PB-1102	922177	771329	Thickness (ft)	18	5	5	20	62	48	20	19	21	15	g
			Litho	18	1	1	1	1	4	4	4	1	1	
			HK (ft/day)	18	25	50	50	50	1500	1600	1600	10	10	
PB-1101	943750	752690	Thickness (ft)	19	5	5	25	20	65	20	40	40	80	g
			Litho	19	1	1	1	1	3	5	5	5	5	
			HK (ft/day)	19	25	50	50	50	1600	1600	1600	100	50	
PB-1104	943671	768845	Thickness (ft)	20	5	5	25	20	65	20	40	40	80	g
			Litho	20	1	1	1	1	4	5	5	5	5	
			HK (ft/day)	20	25	50	50	50	850	1600	1600	100	50	
PB-1107	910957	777015	Thickness (ft)	15	4	7	13	33	48	24	11	9	20	g
			Litho	15	2	5	5	1	5	5	4	5	5	
			HK (ft/day)	15	25	50	50	50	500	50	5	10	1	
WCA2A-F1	862657	737379	Thickness (ft)	10	6	3	11	16	17	4	60	30	30	e
			Litho	10	2	5	5	5	5	5	5	5	3	
			HK (ft/day)	10	25	61	24	500	5	5	55	400	5	

Well	X^h	Y^h		Ground Elevation (NGVD)	Holocene	Q5	Q4	Q3	Q2	Q1	T1	T2	T3	Source
WCA2A-F4	857577	721376	Thickness (ft)	10	6	3	11	16	17	4	60	30	30	e
			Litho	10	2	5	5	5	5	5	5	5	3	
			HK (ft/day)	10	25	180	25	500	5	5	55	400	5	
WCA2A-U3	849010	710620	Thickness (ft)	10	6	3	11	16	17	4	60	30	30	e
			Litho	10	2	5	5	5	5	5	5	5	3	
			HK (ft/day)	10	25	61	24	500	5	5	55	400	5	
WCA2A-U1	867362	693782	Thickness (ft)	10	6	3	11	16	17	4	60	30	30	e
			Litho	10	2	5	5	5	5	5	5	5	3	
			HK (ft/day)	10	25	61	5	45	5	5	55	400	5	
G-563	931335	657967	Thickness (ft)	13	3	10	24	34	39	44	27	40	80	
			Litho	13	1	1	1	7	3	5	5	5	1	
			HK (ft/day)	13	25	25	25	25	1000	1000	50	75	50	
G-3318	785088	381496	Thickness (ft)	8	6	8	9	13	6	4	94	30	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	20000	20000	20000	5	300	1	
G-3394	766917	422736	Thickness (ft)	8	6	4	6	12	8	5	95	25	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	42000	42000	42000	5	500	1	
G-3309	763742	484207	Thickness (ft)	8	6	2	2	2	4	6	78	34	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	50	50	50	20000	20000	5	500	1	
G-3302	753416	519315	Thickness (ft)	8	6	2	6	4	2	8	53	77	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	5	5	5	5	450	450	5	500	1	
G-3395	843182	328604	Thickness (ft)	8	6	8	10	14	16	20	60	60	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	

Well	X^h	Y^h		Ground Elevation (NGVD)	Holocene	Q5	Q4	Q3	Q2	Q1	T1	T2	T3	Source
			HK (ft/day)	8	25	10000	10000	20000	20000	20000	5	5	1	
G-3324	836249	362696	Thickness (ft)	8	6	6	8	12	16	22	40	40	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	24000	24000	24000	5	5	1	
G-3320	831330	399725	Thickness (ft)	8	6	12	14	26	14	24	30	10	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	75000	75000	75000	5	5	1	
G-3315	833215	432441	Thickness (ft)	8	6	10	22	14	18	16	80	10	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	27000	27000	27000	5	5	1	
G-3311	821892	471467	Thickness (ft)	8	6	7	6	11	11	14	82	32	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	20000	20000	42000	150	500	1	
G-3304	820248	519213	Thickness (ft)	8	6	9	8	12	8	6	70	25	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	20000	40000	40000	300	500	1	
G-3323	813694	357966	Thickness (ft)	8	6	4	10	9	9	7	30	0	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	20000	30000	30000	1000	0	1	
G-3319	796785	394756	Thickness (ft)	8	6	5	4	12	12	15	100	10	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	20000	55000	55000	5	500	1	
G-3314	801448	426768	Thickness (ft)	8	6	2	12	16	8	15	120	35	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	37000	37000	37000	5	100	1	
G-3310	793621	468139	Thickness (ft)	8	6	3	13	7	11	10	114	25	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	29000	29000	29000	30	500	1	

Well	X^h	Y^h		Ground Elevation (NGVD)	Holocene	Q5	Q4	Q3	Q2	Q1	T1	T2	T3	Source
G-3303	786327	519703	Thickness (ft)	8	6	7	4	6	8	6	82	30	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	50	50	5000	40000	40000	5	500	1	
G-3312	859574	477280	Thickness (ft)	8	6	4	12	22	18	20	60	20	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	3300	3300	3300	3300	3300	400	5	1	
G-3305	858978	506959	Thickness (ft)	8	6	11	16	24	14	12	45	20	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	15000	15000	15000	250	5	1	
G-3321	868207	394941	Thickness (ft)	8	6	16	10	12	21	23	40	20	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	20000	20000	20000	500	5	1	
G-3316	860548	425595	Thickness (ft)	8	6	12	8	14	22	16	40	20	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	20000	20000	20000	50	5	1	
G-3313	886668	476304	Thickness (ft)	8	6	20	10	34	36	10	40	20	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	3300	3300	8700	8700	8700	50	5	1	
G-3307	908565	519535	Thickness (ft)	8	6	17	9	34	23	17	45	30	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	3300	3300	8700	8700	8700	500	500	1	
G-3306	888714	521646	Thickness (ft)	8	6	8	7	27	20	26	60	20	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	3300	3300	8700	8700	8700	100	5	1	
G-3301	713283	518739	Thickness (ft)	8	3	1	1	1	2	9	53	70	1	b,d
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	5	5	5	5	450	450	200	500	1	
LARGO	863985	313059	Thickness (ft)	8	6	10	16	50	20	22	30	50	1	

Well	X^h	Y^h		Ground Elevation (NGVD)	Holocene	Q5	Q4	Q3	Q2	Q1	T1	T2	T3	Source
			Lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	25	10000	10000	20000	20000	20000	50	500	1	
MO-177	674500	516900	Thickness (ft)	8	4	1	1	1	1	1	1	78	1	f
			lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	10	1	1	1	1	1	5	3800	1	
MO-178	674500	517900	Thickness (ft)	8	4	1	1	1	1	1	40	80	1	f
			lith1	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	10	10	10	50	50	50	5	1125	1	
C-1134	681600	557500	Thickness (ft)	10	1	1	1	1	1	1	1	77	1	f
			lith1	10	0	1	1	1	1	0	0	0	1	
			HK (ft/day)	10	10	1	1	1	1	1	1	2600	1	
C-1138	680800	600000	Thickness (ft)	11	2	1	1	1	1	1	18	87	1	f
			lith1	11	0	1	1	1	1	0	0	0	1	
			HK (ft/day)	11	10	1	1	1	1	1	5	850	1	
C-1169	683300	687800	Thickness (ft)	11	5	1	1	1	1	1	70	63	1	f
			lith1	11	0	1	1	1	1	1	0	0	1	
			HK (ft/day)	11	5	1	1	1	1	1	5	1111	1	
HE-1110	679100	748300	Thickness (ft)	15	5	1	1	1	1	1	30	113	1	f
			lith1	15	0	1	1	1	1	1	0	0	1	
			HK (ft/day)	15	5	1	1	1	1	1	5	265	1	
HE-1116	672800	798800	Thickness (ft)	18	1	2	2	2	2	2	35	106	1	f
			lith1	18	0	0	0	0	0	1	0	0	1	
			HK (ft/day)	18	25	25	25	25	25	25	5	189	1	
PB-1703	719800	755500	Thickness (ft)	6	2	2	2	2	2	2	55	73	1	f
			lith1	6	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	6	25	25	25	25	25	25	5	82	1	
PB-1704	793200	748900	Thickness (ft)	11	5	8	3	12	14	8	23	84	1	f
			lith1	11	0	0	0	0	0	0	0	0	1	

Well	X^h	Y^h		Ground Elevation (NGVD)	Holocene	Q5	Q4	Q3	Q2	Q1	T1	T2	T3	Source
			HK (ft/day)	11	25	50	50	50	50	50	5	595	1	
G-3295	709100	574000	Thickness (ft)	11	1	1	1	1	1	1	52	76	1	b,d
			lith1	11	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	11	5	5	5	5	5	5	5	500	1	
G-2346	701200	605600	Thickness (ft)	11	1	1	1	1	1	1	52	76	1	a,c
			lith1	11	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	11	5	5	5	5	5	5	5	500	1	
G-3308	712500	468000	Thickness (ft)	4	2	3	2	2	3	3	92	45	1	b,d
			lith1	4	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	4	25	55	55	55	55	55	5	500	1	
G-3317	730400	401800	Thickness (ft)	4	2	6	9	3	1	7	58	37	1	b,d
			lith1	4	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	4	25	2000	2000	2000	2000	2000	5	500	1	
G-3322	722000	347000	Thickness (ft)	2	2	3	2	2	2	6	64	30	1	b,d
			lith1	2	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	2	25	2000	2000	2000	2000	2000	5	500	1	
G-2338	705800	642000	Thickness (ft)	11	2	3	3	3	3	3	70	45	1	b,d
			lith1	11	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	11	25	55	55	55	55	55	5	1300	1	
G-2329	702400	667400	Thickness (ft)	11	2	3	3	3	3	3	70	45	1	b,d
			lith1	11	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	11	25	55	55	55	55	55	5	1700	1	
G-2340	712000	706000	Thickness (ft)	11	2	3	3	3	3	3	70	45	1	a,c
			lith1	11	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	11	25	55	55	55	55	55	75	1000	1	
G-2314	712500	726000	Thickness (ft)	11	2	3	3	3	3	3	70	45	1	a,c
			lith1	11	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	11	25	55	55	55	55	55	75	500	1	

Well	X^h	Y^h		Ground Elevation (NGVD)	Holocene	Q5	Q4	Q3	Q2	Q1	T1	T2	T3	Source
G-2320	752500	660000	Thickness (ft)	11	4	9	9	9	9	9	20	104	1	
			lith1	11	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	11	25	25	500	25	250	2250	5	846	1	
FPL-MA	814902	984313	Thickness (ft)	35	2	3	15	10	30	20	40	50	1	
			lith1	35	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	35	50	50	50	50	50	50	50	50	1	
W12668	870233	989843	Thickness (ft)	35	2	8	10	20	30	20	40	50	1	
			lith1	35	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	35	50	50	50	50	50	50	50	50	1	
L-35TW1	884236	672123	Thickness (ft)	8	5	5	12	24	30	13	53	30	50	
			Litho	8	1	4	4	1	3	5	7	5	1	
			HK (ft/day)	8	25	50	50	50	750	24000	250	5	1	
PB-674	945716	782693	Thickness (ft)	17	5	5	22	24	59	30	55	35	30	g
			Litho	17	1	1	1	7	4	4	4	4	7	
			HK (ft/day)	17	25	50	50	50	850	50	10	10	1	
PB-840	777116	770864	Thickness (ft)	15	5	5	10	10	10	10	90	80	40	
			Litho	15	2	5	5	5	5	5	4	4	4	
			HK (ft/day)	15	25	5	10	10	10	10	5	10	1	
I-95PB	950300	898648	Thickness (ft)	15	5	10	10	10	5	5	74	88	5	
			Litho	15	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	15	25	10	10	10	10	10	14	25	1	
W16182	903857	870878	Thickness (ft)	15	5	10	10	10	5	5	60	80	10	
			Litho	15	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	15	25	10	10	10	10	10	14	25	1	
W16193	870324	902802	Thickness (ft)	15	4	5	5	5	5	5	50	60	5	
			Litho	15	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	15	25	10	10	10	10	10	25	130	1	
W17037	869541	949045	Thickness (ft)	25	7	4	2	14	15	13	15	79	5	

Well	X^h	Y^h		Ground Elevation (NGVD)	Holocene	Q5	Q4	Q3	Q2	Q1	T1	T2	T3	Source
			Litho	25	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	25	25	10	10	10	10	10	10	10	1	
W17052	764969	896737	Thickness (ft)	10	10	4	4	4	4	4	60	50	5	
			Litho	10	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	10	10	10	10	10	10	10	10	130	1	
W17606	881480	900640	Thickness (ft)	15	4	10	4	6	10	10	47	63	5	
			Litho	15	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	15	25	10	10	10	10	10	25	130	1	
W17607	887499	918848	Thickness (ft)	15	5	5	5	5	5	5	50	90	5	
			Litho	15	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	15	25	10	10	10	10	10	25	75	1	
W20	887499	918848	Thickness (ft)	15	8	5	5	6	6	6	60	50	5	
			Litho	15	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	15	10	10	10	10	10	10	10	130	1	
PB1510	949200	852089	Thickness (ft)	20	4	4	12	6	25	20	63	85	5	
			Litho	20	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	20	10	10	10	10	10	10	50	1100	1	
OCEAN1	980000	850000	Thickness (ft)	5	5	10	20	20	25	20	25	100	5	
			Litho	5	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	5	25	50	50	50	50	50	50	50	1	
SiteHC	915386	1031363	Thickness (ft)	10	5	10	14	13	30	38	10	6	5	
			Litho	10	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	10	25	50	50	50	50	50	50	50	1	
HSP8918	921736	971513	Thickness (ft)	14	5	5	11	30	30	34	30	25	5	
			Litho	14	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	14	2	2	2	25	25	25	36	36	1	
M1015	914470	986059	Thickness (ft)	15	5	5	5	40	40	40	30	30	5	
			Litho	15	0	0	0	0	0	0	0	0	1	

Well	X^h	Y^h		Ground Elevation (NGVD)	Holocene	Q5	Q4	Q3	Q2	Q1	T1	T2	T3	Source
			HK (ft/day)	15	13	13	13	25	25	25	25	25	1	
JDSP	928086	979688	Thickness (ft)	12	10	10	10	30	30	30	50	52	5	
			Litho	12	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	12	13	13	13	25	25	25	25	25	1	
HSMW4	937236	989163	Thickness (ft)	40	10	10	10	45	45	41	50	21	5	
			Litho	40	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	40	13	13	13	25	25	25	25	25	1	
M1253	905386	1014563	Thickness (ft)	17	15	15	10	30	30	35	10	5	5	
			Litho	17	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	17	13	13	13	25	25	25	25	25	1	
M1017	914174	1018674	Thickness (ft)	15	10	10	15	20	20	20	50	50	5	
			Litho	15	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	15	13	13	13	25	25	25	50	25	1	
M1229	932985	962651	Thickness (ft)	10	2	10	10	33	33	33	25	5	5	
			Litho	10	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	10	5	5	5	25	25	25	25	25	1	
M1230	942470	964837	Thickness (ft)	8	5	10	10	30	35	35	4	5	5	
			Litho	8	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	8	30	30	30	60	60	60	56	56	1	
PB1607	924443	926544	Thickness (ft)	18	15	10	10	33	33	33	10	25	5	
			Litho	18	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	18	13	13	13	25	25	25	25	25	1	
PB1546	906483	946425	Thickness (ft)	20	3	5	10	25	25	25	10	55	5	
			Litho	20	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	20	13	13	13	25	25	25	25	25	1	
M1096	891527	965926	Thickness (ft)	22	4	10	10	20	10	10	40	42	5	
			Litho	22	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	22	13	13	13	25	25	25	25	25	1	

Well	X^h	Y^h		Ground Elevation (NGVD)	Holocene	Q5	Q4	Q3	Q2	Q1	T1	T2	T3	Source
MPLWO	941987	939363	Thickness (ft)	14	15	15	20	30	30	35	60	55	5	
			Litho	14	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	14	30	30	30	50	50	50	50	50	1	
M1053	925000	1025000	Thickness (ft)	15	10	10	10	20	20	20	50	40	5	
			Litho	15	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	15	25	25	25	25	25	25	25	50	1	
M1013	895000	1050000	Thickness (ft)	15	10	10	10	20	20	20	50	40	5	
			Litho	15	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	15	25	25	25	25	25	50	25	25	1	
M1043	908000	1054000	Thickness (ft)	30	20	15	15	20	20	20	50	40	5	
			Litho	15	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	15	25	25	25	50	50	50	50	50	1	
M1023	914174	1018674	Thickness (ft)	15	10	10	10	20	20	20	50	40	5	
			Litho	15	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	15	25	25	25	50	50	50	25	25	1	
M1014	938500	988500	Thickness (ft)	15	10	10	10	20	20	20	50	40	65	
			Litho	15	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	15	25	25	25	25	50	25	25	25	1	
M1091	904000	1041000	Thickness (ft)	15	10	10	10	20	20	20	50	40	15	
			Litho	15	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	15	25	25	25	25	50	50	50	50	1	
PBAGG	863075	865650	Thickness (ft)	16	5	20	15	10	20	20	30	30	15	
			Litho	16	0	0	0	0	0	0	0	0	1	
			HK (ft/day)	16	5	5	5	20	20	20	20	20	1	

Note: NGVD = National Geodetic Vertical Datum; HK = Horizontal Hydraulic Conductivity (ft/day); Holo = Holocene unit; Q5 = Pamlico Sand unit; Q4 = Miami Limestone unit; Q3 = Fort Thompson Formation unit; Q2 = Anastasia Formation unit; Q1 = Key Largo Limestone unit; T1 = Pinecrest Sand Member; T2 = Ochopee Limestone Member; T3 = Top of Peace River Formation.

a. Data adapted from Causaras 1985.

b. Data adapted from Causaras 1987.
c. Data adapted from Fish 1988.
d. Data adapted from Fish and Stewart 1991.
e. Data adapted from Harvey *et al*. 2002
f. Data adapted from Reese and Cunningham 2000.
g. Data adapted from Shine, Padgett and Barfknecht 1989.
h. Location in Florida East State Plane coordinates, NAD 1983 Datum.

Table 30. Conceptual Model layer Properties

Id	THICKL1	THICKL2	THICKL3	TOP2	TOP3	BOT3	HKL1	HKL2	HKL3
PB-1428	16	64	73	-5	-69	-142	82.81	64.06	100.00
G-2342	36	97	83	-23	-120	-203	15.42	337.89	165.66
G-2323	38	97	34	-26	-123	-157	22.11	274.74	720.59
G-2325	73	80	50	-59	-139	-189	25.00	472.81	150.00
G-2344	49	97	71	-33	-130	-201	22.35	3190.72	482.39
G-2345	29	84	78	-16	-100	-178	22.76	336.01	692.31
G-2322	34	70	100	-21	-91	-191	45.59	8005.00	260.00
G-2321	19	54	100	-13	-67	-167	22.37	4759.26	11.00
G-2319	13	33	107	-5	-38	-145	276.15	7311.82	240.09
G-2320	12	30	119	-4	-34	-153	45.83	959.83	635.38
G-2327	24	99	53	-18	-117	-170	46.88	3580.30	136.79
G-2318	20	69	50	-14	-83	-133	46.25	4518.12	403.00
G-2317	11	64	56	-4	-68	-124	33.18	14312.50	2.14
G-2341	19	87	30	-7	-94	-124	11.32	50.00	163.33
G-2312	13	26	112	-6	-32	-144	44.23	27.50	296.43
G-2347	37	90	79	-31	-121	-200	30.08	10000.00	626.58
G-2315	24	24	106	-10	-34	-140	8.33	50.00	205.80
G-2316	13	46	100	-6	-52	-152	257.69	20000.00	335.33
G-2328	46	88	73	-36	-124	-197	32.07	30000.00	132.19
G-2311	19	56	68	-12	-68	-136	116.05	10000.00	5.00
G-3300	36	81	83	-22	-103	-186	48.75	2724.69	750.00
G-2610	62	68	120	-57	-125	-245	53.06	25000.00	237.50
G-3472	45	75	83	-35	-110	-193	1722.22	5553.33	750.00
G-3299	35	72	70	-27	-99	-169	17717.14	7600.00	384.29
G-3298	26	42	94	-17	-59	-153	21542.31	20000.00	276.60
G-3296	15	24	136	-8	-32	-168	11615.00	40000.00	374.26
G-3297	19	37	94	-11	-48	-142	44.74	29000.00	101.06
PB-690	40	105	60	-29	-134	-194	46.88	307.52	10.00
PB-1108	37	68	50	-23	-91	-141	47.30	248.53	6.90
PB-1103	30	110	40	-9	-119	-159	45.83	810.91	825.00
PB-1102	30	130	40	-12	-142	-182	45.83	823.85	765.25
PB-1101	35	105	80	-16	-121	-201	46.43	1304.76	850.00
PB-1104	35	105	80	-15	-120	-200	46.43	840.48	850.00
PB-1107	24	105	20	-9	-114	-134	34.96	255.71	7.25
WCA2A-F1	20	37	90	-10	-47	-137	48.25	219.05	170.00
WCA2A-F4	20	37	90	-10	-47	-137	29.85	219.05	170.00
WCA2A-U3	20	37	90	-10	-47	-137	19.40	219.05	170.00
WCA2A-U1	20	37	90	-10	-47	-137	25.00	22.30	170.00
G-563	37	117	67	-24	-141	-208	9191.22	716.67	64.93
G-3318	23	23	124	-15	-38	-162	7397.83	20000.00	76.37
G-3394	16	25	120	-8	-33	-153	40.63	42000.00	108.13
G-3309	10	12	112	-2	-14	-126	5.00	16675.00	155.27
G-3302	14	14	130	-6	-20	-150	5725.00	322.86	298.19

Id	THICKL1	THICKL2	THICKL3	TOP2	TOP3	BOT3	HKL1	HKL2	HKL3
G-3395	24	50	120	-16	-66	-186	7506.25	20000.00	5.00
G-3324	20	50	80	-12	-62	-142	7007.50	24000.00	5.00
G-3320	32	64	40	-24	-88	-128	8129.69	75000.00	5.00
G-3315	38	48	90	-30	-78	-168	8425.00	27000.00	5.00
G-3311	19	36	114	-11	-47	-161	6850.00	28555.56	248.25
G-3304	23	26	95	-15	-41	-136	7397.83	30769.23	352.63
G-3323	20	25	30	-12	-37	-67	7007.50	26400.00	1000.00
G-3319	15	39	110	-7	-46	-156	6010.00	44230.77	50.00
G-3314	20	39	155	-12	-51	-206	7007.50	37000.00	26.45
G-3310	22	28	139	-14	-42	-181	43.18	29000.00	114.53
G-3303	17	20	112	-9	-29	-141	2144.12	29500.00	137.59
G-3312	22	60	80	-14	-74	-154	7279.55	3300.00	301.25
G-3305	33	50	65	-25	-75	-140	8186.36	15000.00	174.62
G-3321	32	56	60	-24	-80	-140	8129.69	20000.00	335.00
G-3316	26	52	60	-18	-70	-130	2544.23	20000.00	35.00
G-3313	36	80	60	-28	-108	-168	2754.17	8700.00	35.00
G-3307	32	74	75	-24	-98	-173	2685.94	8700.00	500.00
G-3306	21	73	80	-13	-86	-166	5.00	8700.00	76.25
G-3301	5	12	123	3	-9	-132	4015.00	412.92	370.73
LARGO	32	92	80	-24	-116	-196	2.69	20000.00	331.25
MO-177	6	3	79	2	-1	-80	10.00	1.00	3751.96
MO-178	6	3	120	2	-1	-121	7.00	50.00	751.67
C-1134	3	3	78	7	4	-74	4.00	1.00	2566.68
C-1138	4	3	105	7	4	-101	3.00	1.00	705.14
C-1169	7	3	133	4	1	-132	3.86	1.00	528.89
HE-1110	7	3	143	8	5	-138	25.00	1.00	210.45
HE-1116	5	6	141	13	7	-134	25.00	25.00	143.33
PB-1703	6	6	128	0	-6	-134	41.67	25.00	48.91
PB-1704	16	34	107	-5	-39	-146	5.00	50.00	468.18
G-3295	3	3	128	8	5	-123	5.00	5.00	298.91
G-2346	3	3	128	8	5	-123	45.00	5.00	298.91
G-3308	7	8	137	-3	-11	-148	1435.71	55.00	167.59
G-3317	17	11	95	-13	-24	-119	1767.65	2000.00	197.79
G-3322	7	10	94	-5	-15	-109	46.43	2000.00	162.98
G-2338	8	9	115	3	-6	-121	47.50	55.00	511.74
G-2329	8	9	115	3	-6	-121	47.50	55.00	668.26
G-2340	8	9	115	3	-6	-121	47.50	55.00	436.96
G-2314	8	9	115	3	-6	-121	203.13	55.00	241.30
G-2320	22	27	124	-11	-38	-162	50.00	841.67	710.35
FPL-MA	20	60	90	15	-45	-135	50.00	50.00	50.00
W12668	20	70	90	15	-55	-145	47.50	50.00	50.00
L-35TW1	22	67	83	-14	-81	-164	44.32	5010.45	161.45
PB-674	32	113	90	-15	-128	-218	11.56	467.70	10.00
PB-840	20	30	170	-5	-35	-205	13.75	10.00	7.35
I-95PB	25	20	162	-10	-30	-192	13.00	10.00	19.98
W16182	25	20	140	-10	-30	-170	13.00	10.00	20.29

Id	THICKL1	THICKL2	THICKL3	TOP2	TOP3	BOT3	HKL1	HKL2	HKL3
W16193	14	15	110	1	-14	-124	14.29	10.00	82.27
W17037	13	42	94	12	-30	-124	10.00	10.00	10.00
W17052	18	12	110	-8	-20	-130	18.33	10.00	64.55
W17606	18	26	110	-3	-29	-139	13.33	10.00	85.14
W17607	15	15	140	0	-15	-155	10.00	10.00	57.14
W20	18	18	110	-3	-21	-131	10.00	10.00	64.55
PB1510	20	51	148	0	-51	-199	45.00	10.00	653.04
OCEAN1	35	65	125	-30	-95	-220	46.43	50.00	50.00
SiteHC	29	81	16	-19	-100	-116	2.00	50.00	50.00
HSP8918	21	94	55	-7	-101	-156	13.00	25.00	36.00
M1015	15	120	60	0	-120	-180	13.00	25.00	25.00
JDSP	30	90	102	-18	-108	-210	13.00	25.00	25.00
HSMW4	30	131	71	10	-121	-192	13.00	25.00	25.00
M1253	40	95	15	-23	-118	-133	13.00	25.00	25.00
M1017	35	60	100	-20	-80	-180	5.00	25.00	37.50
M1229	22	99	30	-12	-111	-141	30.00	25.00	25.00
M1230	25	100	9	-17	-117	-126	13.00	60.00	56.00
PB1607	35	99	35	-17	-116	-151	13.00	25.00	25.00
PB1546	18	75	65	2	-73	-138	13.00	25.00	25.00
M1096	24	40	82	-2	-42	-124	30.00	25.00	25.00
MPLWO	50	95	115	-36	-131	-246	25.00	50.00	50.00
M1053	30	60	90	-15	-75	-165	25.00	25.00	36.11
M1013	30	60	90	-15	-75	-165	25.00	33.33	25.00
M1043	50	60	90	-35	-95	-185	25.00	50.00	50.00
M1023	30	60	90	-15	-75	-165	25.00	50.00	25.00
M1014	30	60	90	-15	-75	-165	25.00	33.33	25.00
M1091	30	60	90	-15	-75	-165	5.00	41.67	50.00
PBAGG	40	50	60	-24	-74	-134	0.00	20.00	20.00

Table 31. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1986 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.64	3.97	4.77	6.00	6.06	5.55	5.77	5.34	4.60	4.14	3.13	2.99	55.96
LaBell	358604.7026	884557.3360	3.59	3.91	5.04	6.35	6.53	5.65	5.75	5.20	4.61	4.11	3.13	2.97	56.84
DevGar	456430.6735	823760.0332	3.55	3.95	4.88	6.01	6.12	5.51	5.47	4.95	4.47	4.08	3.05	3.02	55.05
FtMyer	216753.2486	818638.2761	3.83	4.10	5.27	6.41	6.62	5.93	6.02	5.70	5.02	4.42	3.44	3.09	59.86
Naples	243068.5551	667012.6770	3.71	3.81	5.29	6.15	6.33	5.72	5.98	5.56	5.05	4.34	3.33	3.08	58.34
EverGl	373931.7692	551332.4951	3.68	3.75	5.50	6.39	6.93	6.21	6.07	5.83	5.50	4.57	3.53	3.30	61.27
Flamin	527565.3021	296766.6878	4.27	4.48	5.73	6.84	6.69	6.11	6.49	5.87	5.23	4.66	3.59	3.45	63.41
Homest	664918.2229	424260.2199	3.75	4.35	4.94	6.32	5.97	5.50	5.94	5.50	4.81	4.48	3.35	2.93	57.82
TTrail	560324.4884	520916.8078	3.78	4.26	4.99	5.77	6.15	5.79	5.83	5.35	4.69	4.12	3.26	3.21	57.20
MIA	730278.4905	539658.9643	4.03	4.49	5.31	6.51	5.87	5.85	6.29	5.72	5.07	4.58	3.40	3.27	60.39
FTL	762547.3199	642814.7394	3.84	4.19	5.03	5.90	5.34	5.40	5.82	5.22	4.56	4.13	3.02	3.08	55.53
WPBIA	793886.7964	855051.2010	3.69	3.95	4.70	5.92	5.38	5.55	5.99	5.17	4.45	3.98	2.97	2.86	54.59
CPoint	619547.8702	920849.7413	3.41	3.73	4.52	5.74	6.02	5.51	5.81	5.33	4.64	4.09	3.13	2.95	54.88
BGlade	619774.8414	842082.8625	3.70	4.07	4.82	6.07	6.09	5.61	5.84	5.45	4.77	4.30	3.25	2.93	56.89
MHaven	472835.4991	908545.4085	3.79	4.13	4.94	6.19	6.07	5.54	5.67	5.24	4.40	4.03	3.01	3.10	56.11
Okee	554174.6483	1041865.2140	3.83	4.12	4.99	6.17	5.95	5.35	5.44	5.01	4.21	3.91	2.92	3.11	55.00
Stuart	770878.6178	1042729.6690	3.56	3.85	4.89	5.98	5.53	5.09	5.59	5.09	4.41	3.89	2.85	3.04	53.75
Vero	688845.9072	1205856.6020	3.58	3.95	4.76	6.01	5.50	5.60	5.88	5.23	4.42	4.00	2.86	2.86	54.64

Table 32. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1987 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.57	3.61	4.60	5.86	5.92	5.66	5.88	5.67	4.81	3.91	3.02	3.15	55.64
LaBell	358604.7026	884557.3360	3.55	3.73	4.56	5.86	5.76	5.60	5.64	5.41	4.59	4.06	3.10	3.21	55.08
DevGar	456430.6735	823760.0332	3.53	3.62	4.50	5.74	5.93	5.84	5.97	5.54	4.85	4.00	3.05	3.24	55.80
FtMyer	216753.2486	818638.2761	3.73	3.84	4.87	5.92	6.49	5.96	6.20	5.77	4.86	4.31	3.27	3.51	58.74
Naples	243068.5551	667012.6770	3.67	3.61	4.64	5.42	6.33	5.77	6.15	5.76	4.89	4.08	3.17	3.47	56.96
EverGl	373931.7692	551332.4951	3.82	3.89	4.97	5.95	6.16	5.98	6.31	6.13	5.00	4.76	3.56	3.70	60.21
Flamin	527565.3021	296766.6878	4.10	3.87	5.33	6.54	6.01	6.07	6.89	6.44	5.39	4.90	3.68	3.64	62.85
Homest	664918.2229	424260.2199	3.89	3.85	4.71	6.24	5.92	5.73	5.75	5.58	4.79	3.96	3.07	3.31	56.80
TTrail	560324.4884	520916.8078	3.69	3.67	4.73	5.67	5.63	5.84	6.09	5.84	4.98	4.05	3.21	3.18	56.57
MIA	730278.4905	539658.9643	4.23	3.83	5.08	6.53	5.75	5.67	5.86	5.80	5.21	4.35	3.28	3.52	59.11
FTL	762547.3199	642814.7394	3.92	3.58	4.71	6.08	5.38	5.08	5.52	5.25	4.92	4.04	3.02	3.13	54.63
WPBIA	793886.7964	855051.2010	3.80	3.59	4.43	6.00	5.27	5.22	5.40	5.39	4.74	3.97	2.89	3.13	53.80
CPoint	619547.8702	920849.7413	3.33	3.35	4.54	5.46	5.89	5.71	5.78	5.59	4.81	3.65	2.89	2.98	53.99
BGlade	619774.8414	842082.8625	3.70	3.71	4.72	6.00	6.09	5.69	5.90	5.76	4.76	3.97	3.15	3.37	56.81
MHaven	472835.4991	908545.4085	3.67	3.77	4.53	6.13	5.79	5.57	5.96	5.66	4.85	4.09	3.01	3.11	56.13
Okee	554174.6483	1041865.2140	3.73	3.81	4.59	6.15	5.67	5.34	5.70	5.40	4.64	4.06	3.02	3.15	55.25
Stuart	770878.6178	1042729.6690	3.78	3.93	4.86	6.15	5.14	5.04	5.41	4.80	4.01	3.99	3.03	2.98	53.10
Vero	688845.9072	1205856.6020	3.66	3.65	4.51	5.79	5.32	5.10	5.72	5.24	4.55	3.70	2.81	3.09	53.14

Table 33. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1988 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.19	3.75	4.85	5.94	6.07	5.50	5.68	5.30	4.54	4.30	3.31	3.23	55.65
LaBell	358604.7026	884557.3360	3.40	3.99	5.08	5.73	6.07	5.49	5.57	5.22	4.50	4.53	3.37	3.37	56.33
DevGar	456430.6735	823760.0332	3.39	4.23	5.33	6.20	6.60	5.96	5.83	5.47	4.68	4.49	3.36	3.47	59.00
FtMyer	216753.2486	818638.2761	3.53	4.25	5.32	5.90	6.51	6.19	6.17	5.78	4.91	4.73	3.62	3.70	60.62
Naples	243068.5551	667012.6770	3.45	4.16	5.20	5.51	6.04	5.82	5.92	5.86	4.79	4.58	3.45	3.59	58.36
EverGl	373931.7692	551332.4951	3.88	4.64	5.67	6.02	6.71	6.22	6.42	6.00	5.18	5.09	3.97	3.80	63.59
Flamin	527565.3021	296766.6878	3.84	4.47	5.33	6.07	6.24	5.41	5.66	5.26	4.60	4.38	3.23	3.57	58.06
Homest	664918.2229	424260.2199	3.25	4.04	4.74	6.16	5.96	5.49	5.49	5.26	4.45	4.15	3.16	3.28	55.41
TTrail	560324.4884	520916.8078	3.38	3.89	5.06	6.32	6.59	5.48	6.03	5.24	4.64	4.56	3.22	3.60	57.99
MIA	730278.4905	539658.9643	3.56	4.30	4.83	6.14	6.33	5.72	6.04	5.45	4.67	4.67	3.50	3.58	58.80
FTL	762547.3199	642814.7394	3.30	4.06	4.68	5.75	5.98	5.46	5.46	5.20	4.37	4.36	3.19	3.30	55.10
WPBIA	793886.7964	855051.2010	3.20	3.87	4.66	5.92	5.83	5.26	5.41	5.00	4.33	4.06	3.13	3.25	53.91
CPoint	619547.8702	920849.7413	3.06	3.55	4.80	5.81	6.03	5.45	5.67	5.26	4.62	4.12	3.26	2.99	54.61
BGlade	619774.8414	842082.8625	3.25	3.90	4.87	6.05	6.11	5.46	5.68	5.32	4.63	4.41	3.42	3.42	56.51
MHaven	472835.4991	908545.4085	3.25	3.81	4.87	5.96	6.08	5.58	5.69	5.32	4.37	4.37	3.25	3.28	55.83
Okee	554174.6483	1041865.2140	3.36	3.92	4.92	5.89	5.98	5.41	5.46	5.09	4.16	4.27	3.21	3.32	55.00
Stuart	770878.6178	1042729.6690	3.01	4.01	4.64	5.66	5.66	5.19	5.16	4.89	4.20	3.99	3.07	3.13	52.59
Vero	688845.9072	1205856.6020	3.09	3.90	4.55	5.65	5.60	5.33	5.05	4.96	4.20	4.04	3.29	3.21	52.85

Table 34. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1989 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.60	3.98	5.02	5.80	6.36	5.96	5.79	5.50	4.74	4.22	3.58	3.40	57.94
LaBell	358604.7026	884557.3360	3.72	4.01	4.94	5.89	6.46	6.01	5.78	5.31	4.52	4.05	3.49	3.38	57.55
DevGar	456430.6735	823760.0332	3.72	4.14	5.27	6.06	6.67	6.05	5.90	5.66	4.70	4.13	3.59	3.39	59.27
FtMyer	216753.2486	818638.2761	3.92	4.23	5.32	6.21	6.72	6.19	6.22	5.87	4.99	4.38	3.75	3.62	61.41
Naples	243068.5551	667012.6770	3.77	4.09	5.10	5.74	6.30	5.80	5.95	5.60	4.91	4.35	3.65	3.45	58.70
EverGl	373931.7692	551332.4951	3.72	4.06	5.01	5.63	6.12	5.55	5.69	5.33	4.69	4.20	3.57	3.44	56.99
Flamin	527565.3021	296766.6878	3.67	4.06	5.29	5.86	6.07	5.51	6.35	5.32	4.35	4.34	3.32	3.75	57.88
Homest	664918.2229	424260.2199	3.76	4.01	5.36	5.72	6.35	5.62	5.71	5.51	4.95	4.36	3.62	3.56	58.53
TTrail	560324.4884	520916.8078	3.96	4.38	5.87	6.53	7.39	6.99	6.50	6.05	5.18	4.34	3.54	3.74	64.47
MIA	730278.4905	539658.9643	3.93	4.18	5.23	5.92	6.48	5.58	5.96	5.82	4.98	4.65	3.69	3.98	60.38
FTL	762547.3199	642814.7394	3.57	3.87	4.79	5.55	6.05	5.33	5.61	5.42	4.57	4.35	3.34	3.70	56.12
WPBIA	793886.7964	855051.2010	3.49	3.92	4.84	5.49	5.90	5.53	5.65	5.43	4.50	4.15	3.28	3.70	55.87
CPoint	619547.8702	920849.7413	3.52	3.88	4.94	5.67	6.20	5.91	5.79	5.45	4.74	4.19	3.51	3.28	57.08
BGlade	619774.8414	842082.8625	3.69	4.02	5.01	5.77	6.24	5.83	5.69	5.44	4.76	4.29	3.64	3.43	57.80
MHaven	472835.4991	908545.4085	3.60	4.02	5.11	5.96	6.63	6.15	5.89	5.61	4.70	4.19	3.60	3.47	58.93
Okee	554174.6483	1041865.2140	3.58	4.02	5.09	5.86	6.45	5.92	5.65	5.37	4.49	4.09	3.56	3.55	57.62
Stuart	770878.6178	1042729.6690	3.45	4.01	4.66	5.25	5.97	5.19	5.30	5.16	4.25	4.03	3.27	3.72	54.25
Vero	688845.9072	1205856.6020	3.49	3.79	4.65	5.55	5.95	5.51	5.62	5.27	4.35	3.96	3.33	3.41	54.86

Table 35. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1990 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.62	3.80	5.07	5.70	5.80	5.90	5.85	5.67	4.72	4.01	3.58	3.36	57.09
LaBell	358604.7026	884557.3360	3.51	3.81	5.13	5.71	5.65	5.76	5.67	5.43	4.56	4.10	3.59	3.44	56.37
DevGar	456430.6735	823760.0332	3.59	3.56	5.13	5.87	5.85	5.85	5.75	5.71	4.77	4.00	3.60	3.47	57.12
FtMyer	216753.2486	818638.2761	3.86	4.02	5.56	6.17	6.12	6.24	6.21	5.84	5.06	4.31	3.79	3.68	60.84
Naples	243068.5551	667012.6770	3.69	3.96	5.39	5.82	5.81	5.90	6.02	5.69	4.89	4.25	3.74	3.57	58.71
EverGl	373931.7692	551332.4951	3.63	3.90	5.32	5.71	5.57	5.64	5.76	5.43	4.66	4.08	3.68	3.53	56.90
Flamin	527565.3021	296766.6878	4.00	4.00	5.60	6.27	5.90	6.17	6.35	5.96	5.21	4.57	3.95	3.58	61.56
Homest	664918.2229	424260.2199	3.75	3.89	4.84	5.33	5.47	6.33	6.22	5.90	5.04	4.26	3.55	3.52	58.10
TTrail	560324.4884	520916.8078	4.03	4.28	5.66	6.57	6.93	6.67	6.46	6.13	5.13	4.42	3.75	3.72	63.73
MIA	730278.4905	539658.9643	3.68	3.74	4.95	5.54	5.77	6.06	6.36	6.08	4.95	4.23	3.66	3.40	58.41
FTL	762547.3199	642814.7394	3.43	3.55	4.66	5.36	5.50	5.70	5.97	5.60	4.71	3.97	3.42	3.09	54.95
WPBIA	793886.7964	855051.2010	3.25	3.47	4.51	5.10	5.48	5.65	5.78	5.77	4.63	3.81	3.33	3.41	54.19
CPoint	619547.8702	920849.7413	3.54	3.74	4.94	5.63	5.85	5.92	5.87	5.66	4.76	4.00	3.47	3.27	56.63
BGlade	619774.8414	842082.8625	3.67	3.84	5.07	5.71	5.81	5.90	5.80	5.67	4.81	4.06	3.64	3.38	57.36
MHaven	472835.4991	908545.4085	3.65	3.80	5.22	5.77	5.75	5.88	5.89	5.68	4.59	3.98	3.65	3.45	57.31
Okee	554174.6483	1041865.2140	3.50	3.37	4.59	4.72	5.24	4.71	5.00	5.09	4.34	3.62	3.85	3.18	51.21
Stuart	770878.6178	1042729.6690	3.46	3.63	4.24	4.82	4.88	5.32	5.40	5.34	4.37	3.67	3.23	2.92	51.27
Vero	688845.9072	1205856.6020	3.39	3.38	4.59	4.89	5.32	5.50	5.44	5.42	4.43	3.58	3.14	3.02	52.09

Table 36. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1991 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.33	3.84	5.05	5.20	5.59	5.75	5.88	5.66	4.66	3.98	3.42	3.22	55.58
LaBell	358604.7026	884557.3360	3.51	4.00	5.15	5.72	5.72	5.63	5.58	5.18	4.52	3.89	3.48	3.23	55.61
DevGar	456430.6735	823760.0332	3.62	4.02	5.39	5.74	6.01	5.74	5.82	5.59	4.70	4.06	3.65	3.46	57.80
FtMyer	216753.2486	818638.2761	3.47	3.88	5.13	5.67	6.08	5.99	5.91	5.65	4.98	4.23	3.64	3.50	58.12
Naples	243068.5551	667012.6770	3.42	3.79	4.96	5.45	5.82	5.75	5.92	5.58	4.94	4.20	3.64	3.43	56.90
EverGl	373931.7692	551332.4951	3.64	4.09	5.17	5.78	6.38	5.81	5.95	5.79	5.02	4.59	3.79	3.64	59.63
Flamin	527565.3021	296766.6878	3.84	4.47	4.91	5.84	5.83	6.10	6.13	6.00	5.80	4.97	3.96	3.61	61.46
Homest	664918.2229	424260.2199	3.69	4.24	5.26	5.61	5.73	5.85	5.98	5.86	4.83	4.08	3.43	3.41	57.95
TTrail	560324.4884	520916.8078	3.97	4.35	5.68	6.24	6.41	6.16	5.87	5.41	4.61	3.94	3.48	3.34	59.45
MIA	730278.4905	539658.9643	3.60	4.10	5.15	5.31	5.37	6.08	6.04	5.88	4.89	4.15	3.60	3.37	57.54
FTL	762547.3199	642814.7394	3.30	3.81	4.77	4.90	4.77	5.64	5.50	5.38	4.44	3.84	3.27	3.11	52.72
WPBIA	793886.7964	855051.2010	3.26	3.57	4.94	4.84	4.95	5.53	5.82	5.57	4.48	3.76	3.29	3.19	53.18
CPoint	619547.8702	920849.7413	3.24	3.70	4.93	5.14	5.56	5.66	5.82	5.63	4.65	3.98	3.34	3.15	54.81
BGlade	619774.8414	842082.8625	3.30	3.81	5.00	5.23	5.62	5.83	5.95	5.80	4.84	4.17	3.50	3.35	56.37
MHaven	472835.4991	908545.4085	3.45	4.01	5.21	5.24	5.61	5.77	5.88	5.55	4.49	3.79	3.42	3.15	55.56
Okee	554174.6483	1041865.2140	3.19	3.73	4.70	5.00	5.21	4.93	4.41	4.65	3.93	3.79	3.33	3.23	50.10
Stuart	770878.6178	1042729.6690	3.27	3.60	4.97	4.53	4.47	5.47	5.76	5.58	4.46	3.70	3.24	3.12	52.16
Vero	688845.9072	1205856.6020	3.21	3.48	4.81	4.69	5.13	5.29	5.56	5.29	4.16	3.64	3.17	3.13	51.54

Table 37. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1992 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.55	3.93	4.97	5.25	6.32	5.37	5.81	5.38	4.41	4.07	3.07	3.25	55.39
LaBell	358604.7026	884557.3360	3.59	4.09	5.25	5.24	6.30	5.46	5.58	5.27	4.31	3.82	2.71	3.05	54.66
DevGar	456430.6735	823760.0332	3.70	4.19	5.39	5.26	6.85	6.06	6.20	5.25	4.28	3.85	3.18	3.25	57.45
FtMyer	216753.2486	818638.2761	3.66	4.06	5.23	5.54	6.57	5.50	6.11	5.58	4.80	4.27	3.39	3.53	58.22
Naples	243068.5551	667012.6770	3.56	3.88	5.07	5.54	6.37	5.42	5.90	5.52	4.96	4.31	3.32	3.51	57.36
EverGl	373931.7692	551332.4951	4.15	4.23	5.72	6.05	6.81	5.11	5.61	5.26	4.03	4.03	3.21	3.48	57.68
Flamin	527565.3021	296766.6878	3.95	4.30	5.79	6.30	7.24	6.07	6.07	4.94	5.18	4.01	3.48	3.85	61.19
Homest	664918.2229	424260.2199	3.74	4.14	5.48	5.60	6.84	5.69	5.97	5.53	5.55	4.08	3.22	3.61	59.44
TTrail	560324.4884	520916.8078	3.78	4.32	5.55	6.06	7.20	5.85	5.70	5.60	5.56	3.79	3.13	3.25	59.79
MIA	730278.4905	539658.9643	3.87	4.09	5.39	5.39	6.62	5.92	5.88	5.58	4.61	4.20	3.19	3.48	58.21
FTL	762547.3199	642814.7394	3.58	3.90	4.94	5.04	5.99	5.53	5.52	5.25	4.26	4.10	2.94	3.21	54.26
WPBIA	793886.7964	855051.2010	3.55	3.89	4.93	5.00	6.27	5.66	5.88	5.25	4.26	3.98	3.00	3.04	54.71
CPoint	619547.8702	920849.7413	3.44	3.83	4.81	5.20	6.21	5.40	5.81	5.37	4.41	3.97	3.03	3.14	54.61
BGlade	619774.8414	842082.8625	3.65	4.03	5.02	5.37	6.49	5.37	5.87	5.37	4.45	4.16	3.14	3.33	56.23
MHaven	472835.4991	908545.4085	3.56	3.93	5.08	5.18	6.27	5.34	5.76	5.41	4.37	4.08	3.04	3.29	55.30
Okee	554174.6483	1041865.2140	3.83	4.01	5.07	5.18	6.44	4.64	5.36	4.28	3.96	3.91	3.01	3.11	52.79
Stuart	770878.6178	1042729.6690	3.54	4.00	4.91	4.88	5.81	5.25	5.31	5.05	4.07	4.00	2.92	3.14	52.87
Vero	688845.9072	1205856.6020	3.51	3.75	4.99	4.91	6.12	5.45	5.57	5.22	4.15	3.78	2.81	3.17	53.44

Table 38. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1993 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.12	3.84	4.85	5.72	5.85	5.67	5.83	5.57	4.68	4.04	3.30	3.41	55.88
LaBell	358604.7026	884557.3360	3.02	3.70	4.88	5.34	5.60	5.47	5.87	5.64	4.50	3.76	3.20	3.35	54.35
DevGar	456430.6735	823760.0332	3.05	3.83	5.12	5.99	6.45	6.14	6.12	5.58	4.65	3.93	3.32	3.43	57.63
FtMyer	216753.2486	818638.2761	3.39	3.88	5.03	5.82	6.26	6.13	5.89	5.50	4.87	4.03	3.42	3.60	57.83
Naples	243068.5551	667012.6770	3.44	3.92	5.09	5.87	6.21	5.75	5.98	5.59	4.93	4.07	3.61	3.51	57.95
EverGl	373931.7692	551332.4951	3.35	4.35	5.31	6.21	6.57	5.97	5.88	5.47	5.13	4.31	3.91	3.99	60.45
Flamin	527565.3021	296766.6878	3.70	4.35	5.43	6.50	6.45	5.47	6.41	5.97	5.07	4.53	3.45	4.13	61.46
Homest	664918.2229	424260.2199	3.45	4.17	5.33	5.95	6.17	5.60	6.15	5.76	4.62	4.05	3.46	3.64	58.35
TTrail	560324.4884	520916.8078	3.16	3.57	4.60	5.20	5.48	5.36	5.61	5.51	4.62	4.04	3.42	3.65	54.22
MIA	730278.4905	539658.9643	3.41	4.05	5.15	5.61	5.54	5.47	6.15	5.74	4.77	4.31	3.53	3.82	57.54
FTL	762547.3199	642814.7394	3.11	3.74	4.79	5.44	5.09	5.12	5.75	5.39	4.58	4.19	3.34	3.64	54.17
WPBIA	793886.7964	855051.2010	3.10	3.74	4.86	5.16	5.19	5.45	5.73	5.34	4.56	3.99	3.11	3.52	53.74
CPoint	619547.8702	920849.7413	3.21	3.75	4.64	5.47	5.80	5.65	5.70	5.51	4.63	3.95	3.19	3.09	54.58
BGlade	619774.8414	842082.8625	3.22	3.97	5.04	5.91	6.12	5.71	5.88	5.72	4.76	4.14	3.40	3.56	57.41
MHaven	472835.4991	908545.4085	2.93	3.81	4.88	5.78	5.63	5.64	5.92	5.48	4.64	4.03	3.31	3.57	55.62
Okee	554174.6483	1041865.2140	3.16	3.95	4.35	5.54	5.95	5.84	5.95	5.55	4.61	3.70	3.37	3.52	55.48
Stuart	770878.6178	1042729.6690	3.02	3.67	4.64	5.30	4.99	5.28	5.59	5.21	4.43	3.87	3.12	3.36	52.47
Vero	688845.9072	1205856.6020	3.08	3.67	4.70	5.24	5.03	5.27	5.86	5.45	4.47	3.97	3.13	3.45	53.34

Table 39. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1994 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.34	3.54	4.89	5.27	6.02	5.49	5.70	5.31	4.40	3.97	3.07	2.91	53.90
LaBell	358604.7026	884557.3360	3.44	4.24	5.02	5.45	6.22	6.05	5.74	5.24	4.41	4.09	3.10	3.23	56.24
DevGar	456430.6735	823760.0332	3.37	3.58	5.36	5.71	6.42	6.14	6.12	5.85	4.76	4.19	3.46	3.32	58.28
FtMyer	216753.2486	818638.2761	3.47	3.72	5.15	5.73	6.31	5.93	5.98	5.56	4.54	4.18	3.39	3.18	57.11
Naples	243068.5551	667012.6770	3.46	3.68	5.01	5.49	5.84	5.91	5.97	5.44	4.57	4.06	3.27	3.17	55.85
EverGl	373931.7692	551332.4951	3.94	4.14	5.70	5.90	6.63	6.38	6.15	5.42	4.67	4.24	3.14	3.09	59.40
Flamin	527565.3021	296766.6878	3.85	3.97	5.60	6.05	6.55	5.74	6.06	6.06	4.97	4.70	3.96	3.25	60.74
Homest	664918.2229	424260.2199	3.57	3.95	5.48	5.88	6.60	6.04	6.49	5.80	4.39	4.52	3.09	3.44	59.25
TTrail	560324.4884	520916.8078	3.45	4.02	5.39	5.56	6.40	5.85	5.71	5.55	4.60	3.84	3.05	2.93	56.36
MIA	730278.4905	539658.9643	3.46	3.51	5.28	5.14	6.06	5.68	5.65	5.41	4.49	4.27	3.19	3.28	55.41
FTL	762547.3199	642814.7394	3.25	3.31	4.94	4.77	5.74	5.24	4.63	5.11	4.22	3.96	2.90	3.11	51.19
WPBIA	793886.7964	855051.2010	3.47	3.60	5.28	5.06	5.94	5.48	5.69	5.38	4.59	4.08	3.12	3.27	54.96
CPoint	619547.8702	920849.7413	3.23	3.39	4.48	5.19	5.79	5.41	5.78	5.33	4.51	4.09	3.13	2.97	53.30
BGlade	619774.8414	842082.8625	3.38	3.66	5.07	5.40	6.06	5.48	5.76	5.34	4.58	4.10	3.17	3.05	55.05
MHaven	472835.4991	908545.4085	3.41	3.57	5.12	5.24	6.21	5.57	5.54	5.25	4.12	3.72	2.90	2.71	53.35
Okee	554174.6483	1041865.2140	3.34	3.67	5.31	4.92	5.73	5.65	5.28	5.04	4.21	3.80	2.99	2.74	52.67
Stuart	770878.6178	1042729.6690	3.21	3.50	4.85	4.67	5.80	5.19	5.12	5.17	4.37	3.93	3.05	3.07	51.94
Vero	688845.9072	1205856.6020	3.17	3.34	4.91	4.61	5.69	5.40	5.67	5.21	4.21	3.74	2.85	2.81	51.60

Table 40. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1995 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.52	3.77	4.85	5.15	5.94	5.41	5.59	5.05	4.49	3.63	3.27	3.14	53.80
LaBell	358604.7026	884557.3360	3.64	3.66	4.92	5.46	5.77	5.89	5.43	5.33	4.38	3.92	3.36	3.07	54.81
DevGar	456430.6735	823760.0332	3.70	4.10	5.41	5.81	6.86	6.27	6.54	5.75	5.05	4.27	3.93	3.66	61.34
FtMyer	216753.2486	818638.2761	3.59	3.95	5.13	5.42	6.19	5.39	5.66	5.04	4.61	3.74	3.47	3.28	55.46
Naples	243068.5551	667012.6770	3.67	3.91	4.96	5.35	5.85	5.40	5.91	5.33	4.56	3.76	3.59	3.33	55.63
EverGl	373931.7692	551332.4951	3.82	4.29	5.26	6.07	6.32	5.90	5.88	5.18	4.68	4.02	3.83	3.51	58.75
Flamin	527565.3021	296766.6878	4.39	4.50	5.14	6.04	6.28	6.19	6.19	5.88	5.02	4.06	4.06	4.03	61.78
Homest	664918.2229	424260.2199	3.77	3.83	5.40	5.96	6.40	5.58	5.62	5.21	4.54	3.68	3.56	3.32	56.87
TTrail	560324.4884	520916.8078	3.52	3.66	4.71	5.18	6.03	5.05	5.92	5.34	4.47	3.85	3.38	3.11	54.21
MIA	730278.4905	539658.9643	3.79	4.04	5.04	5.42	5.82	5.46	5.83	5.50	4.83	3.78	3.67	3.41	56.58
FTL	762547.3199	642814.7394	3.89	4.09	5.06	5.50	5.87	5.45	5.85	5.41	4.81	3.86	3.71	3.54	57.04
WPBIA	793886.7964	855051.2010	3.93	4.20	5.04	5.62	6.04	5.62	5.71	5.39	4.52	3.74	3.73	3.53	57.06
CPoint	619547.8702	920849.7413	3.47	3.74	4.84	5.37	6.05	5.39	5.63	5.15	4.61	3.75	3.28	3.04	54.32
BGlade	619774.8414	842082.8625	3.63	3.90	4.94	5.43	6.03	5.31	5.53	5.03	4.54	3.71	3.37	3.19	54.62
MHaven	472835.4991	908545.4085	3.45	3.68	4.75	4.66	5.75	5.54	5.60	4.95	4.33	3.42	3.16	3.20	52.48
Okee	554174.6483	1041865.2140	3.66	3.94	4.47	4.53	5.18	5.62	5.98	5.38	4.27	3.25	3.41	2.84	52.53
Stuart	770878.6178	1042729.6690	3.82	3.95	4.71	5.09	5.92	5.60	5.76	5.29	4.43	3.54	3.45	3.04	54.61
Vero	688845.9072	1205856.6020	3.23	3.55	4.31	4.75	5.50	5.21	5.57	4.98	4.34	3.48	3.37	3.24	51.53

Table 41. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1996 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.45	4.28	4.85	5.38	5.60	5.50	5.71	5.35	4.81	3.91	3.49	3.40	55.72
LaBell	358604.7026	884557.3360	3.22	3.72	5.03	5.79	5.85	5.47	5.28	5.02	4.43	4.05	3.40	3.35	54.59
DevGar	456430.6735	823760.0332	3.94	4.30	5.57	5.61	6.46	6.14	5.76	6.11	5.30	4.51	3.67	3.92	61.27
FtMyer	216753.2486	818638.2761	3.54	4.25	5.23	5.60	6.04	5.75	5.67	5.44	4.72	3.93	3.58	3.50	57.27
Naples	243068.5551	667012.6770	3.63	4.30	5.25	5.88	5.95	5.75	5.83	5.63	4.69	4.16	3.57	3.49	58.11
EverGl	373931.7692	551332.4951	3.79	4.59	5.46	6.35	6.54	6.31	6.11	6.13	4.87	4.57	3.97	3.76	62.44
Flamin	527565.3021	296766.6878	4.19	4.85	5.70	6.23	6.00	6.12	6.08	6.15	5.22	4.31	3.88	3.96	62.66
Homest	664918.2229	424260.2199	3.80	4.58	5.22	5.50	5.43	5.54	5.68	5.32	4.80	3.77	3.50	3.61	56.75
TTrail	560324.4884	520916.8078	3.56	4.34	5.23	5.74	6.01	5.93	5.90	5.72	4.83	4.10	3.37	3.59	58.30
MIA	730278.4905	539658.9643	3.84	4.70	5.24	5.37	5.71	5.90	5.60	5.58	4.87	3.90	3.27	3.53	57.51
FTL	762547.3199	642814.7394	3.65	4.48	5.13	5.04	5.34	5.61	5.42	5.26	4.75	3.80	3.16	3.37	55.00
WPBIA	793886.7964	855051.2010	3.43	4.42	5.07	5.08	5.17	5.33	5.41	5.20	4.53	3.57	3.08	3.31	53.57
CPoint	619547.8702	920849.7413	3.38	4.09	4.69	5.26	5.63	5.59	5.81	5.45	4.83	3.96	3.46	3.32	55.46
BGlade	619774.8414	842082.8625	3.53	4.26	4.86	5.36	5.61	5.54	5.73	5.38	4.80	3.96	3.55	3.44	56.02
MHaven	472835.4991	908545.4085	3.43	4.48	4.99	5.51	5.58	5.35	5.58	5.23	4.80	3.81	3.46	3.44	55.66
Okee	554174.6483	1041865.2140	3.95	4.44	5.34	5.68	5.31	5.04	5.15	4.91	4.25	3.46	3.09	3.08	53.70
Stuart	770878.6178	1042729.6690	3.51	4.33	5.04	4.99	5.16	5.50	5.34	5.26	4.58	3.77	3.25	3.30	54.03
Vero	688845.9072	1205856.6020	3.47	4.21	5.02	5.13	5.37	5.32	4.99	4.84	4.27	3.36	2.75	3.16	51.88

Table 42. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1997 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.66	3.80	5.05	5.29	5.78	5.45	5.95	5.42	4.47	4.24	3.23	2.99	55.33
LaBell	358604.7026	884557.3360	3.80	3.97	4.99	5.12	5.85	5.73	5.92	5.31	4.27	3.83	3.43	2.98	55.18
DevGar	456430.6735	823760.0332	4.10	4.30	5.39	5.58	5.95	6.35	5.76	5.50	4.52	4.25	3.61	3.20	58.51
FtMyer	216753.2486	818638.2761	4.01	4.15	5.43	5.66	6.31	5.93	6.12	5.72	4.79	4.61	3.62	3.12	59.46
Naples	243068.5551	667012.6770	3.65	3.92	5.01	5.43	5.93	5.75	5.96	5.60	4.76	4.40	3.43	3.05	56.89
EverGl	373931.7692	551332.4951	4.04	4.38	5.41	5.69	6.34	5.58	5.92	5.77	4.71	4.56	3.76	3.30	59.47
Flamin	527565.3021	296766.6878	4.11	3.97	5.69	5.73	6.83	5.69	6.12	5.96	4.94	4.98	3.84	3.47	61.31
Homest	664918.2229	424260.2199	3.87	3.83	5.09	5.08	5.82	5.51	5.90	5.73	4.72	4.27	3.28	3.12	56.21
TTrail	560324.4884	520916.8078	3.84	3.89	5.15	5.63	6.31	5.88	5.97	5.53	4.53	4.12	3.47	3.33	57.64
MIA	730278.4905	539658.9643	3.79	3.64	4.90	5.39	5.79	5.90	5.88	5.69	4.69	4.20	3.40	3.30	56.56
FTL	762547.3199	642814.7394	3.70	3.39	4.63	5.20	5.41	5.65	5.67	5.48	4.52	3.94	3.27	3.15	54.01
WPBIA	793886.7964	855051.2010	3.53	3.29	4.49	5.04	5.32	5.46	5.58	5.43	4.23	3.80	3.21	3.14	52.51
CPoint	619547.8702	920849.7413	3.56	3.72	4.94	5.18	5.76	5.42	5.90	5.51	4.56	4.31	3.18	2.91	54.93
BGlade	619774.8414	842082.8625	3.70	3.82	5.01	5.24	5.74	5.33	5.82	5.43	4.51	4.36	3.25	3.02	55.21
MHaven	472835.4991	908545.4085	3.73	3.86	5.18	5.45	5.85	5.60	6.14	5.32	4.36	4.04	3.26	3.04	55.82
Okee	554174.6483	1041865.2140	3.28	3.47	4.42	4.78	6.45	6.00	6.30	5.53	5.05	3.77	3.39	3.15	55.58
Stuart	770878.6178	1042729.6690	3.47	3.69	4.86	5.47	5.72	5.82	6.04	5.73	4.72	3.92	3.13	3.05	55.61
Vero	688845.9072	1205856.6020	3.32	3.32	4.24	4.89	4.97	5.18	5.52	5.08	3.88	3.57	2.93	2.83	49.71

Table 43. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1998 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.20	3.50	4.67	5.52	6.12	5.89	5.68	5.34	4.37	4.05	3.24	3.08	54.67
LaBell	358604.7026	884557.3360	3.20	3.63	4.61	5.14	5.51	5.88	5.85	5.21	4.11	4.01	3.29	3.18	53.61
DevGar	456430.6735	823760.0332	3.48	3.91	5.12	5.82	6.71	6.46	6.03	5.51	4.56	4.13	3.47	3.32	58.50
FtMyer	216753.2486	818638.2761	3.44	3.73	5.13	5.50	6.37	5.77	5.70	5.61	4.25	4.23	3.50	3.31	56.51
Naples	243068.5551	667012.6770	3.34	3.75	5.20	5.45	6.00	5.75	5.82	5.68	4.37	4.24	3.47	3.27	56.33
EverGl	373931.7692	551332.4951	3.55	3.95	5.06	5.61	5.77	5.51	5.59	5.54	4.13	4.36	3.65	3.47	56.20
Flamin	527565.3021	296766.6878	3.71	4.47	5.54	6.50	7.15	6.70	6.80	6.12	4.83	4.38	3.81	3.81	63.81
Homest	664918.2229	424260.2199	3.07	3.61	4.65	5.38	6.17	5.94	5.83	5.35	4.40	4.08	3.41	3.31	55.19
TTrail	560324.4884	520916.8078	3.36	3.71	4.74	5.49	6.61	6.25	6.07	5.43	4.58	4.01	3.13	3.04	56.44
MIA	730278.4905	539658.9643	3.42	3.76	4.98	5.30	6.27	5.99	6.00	5.60	4.49	3.88	3.31	3.21	56.19
FTL	762547.3199	642814.7394	3.18	3.65	4.65	5.07	6.14	5.90	5.95	5.33	4.44	3.88	3.23	3.00	54.42
WPBIA	793886.7964	855051.2010	3.21	3.65	4.46	4.98	6.16	5.90	5.74	5.17	4.21	3.65	3.23	2.96	53.33
CPoint	619547.8702	920849.7413	3.17	3.49	4.67	5.51	6.08	5.90	5.73	5.40	4.44	4.17	3.24	3.07	54.86
BGlade	619774.8414	842082.8625	3.27	3.63	4.82	5.60	6.08	5.82	5.62	5.30	4.35	4.17	3.29	3.15	55.10
MHaven	472835.4991	908545.4085	3.15	3.38	4.53	5.47	6.19	5.97	5.69	5.33	4.32	3.82	3.19	3.02	54.05
Okee	554174.6483	1041865.2140	3.40	3.73	5.02	5.54	6.15	5.25	5.66	5.41	4.47	4.15	3.01	2.85	54.62
Stuart	770878.6178	1042729.6690	3.10	3.41	4.24	5.15	5.73	5.50	5.57	4.85	4.25	3.69	3.32	2.98	51.79
Vero	688845.9072	1205856.6020	2.93	3.49	4.27	5.00	5.71	5.74	5.57	4.83	3.97	3.45	3.11	2.98	51.05

Table 44. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 1999 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.40	3.97	5.14	5.89	6.33	5.27	5.65	5.34	4.39	3.75	3.36	3.23	55.70
LaBell	358604.7026	884557.3360	3.47	4.04	5.48	6.02	6.46	5.70	5.81	5.02	4.41	3.55	3.14	3.00	56.08
DevGar	456430.6735	823760.0332	3.50	4.04	5.89	6.29	6.83	5.62	5.61	5.61	4.47	3.83	3.19	3.13	58.03
FtMyer	216753.2486	818638.2761	3.69	4.07	5.73	6.02	6.51	5.58	5.61	5.18	4.37	3.93	3.64	3.31	57.63
Naples	243068.5551	667012.6770	3.67	3.99	5.48	5.47	6.13	5.52	5.71	5.21	4.58	4.09	3.55	3.29	56.67
EverGl	373931.7692	551332.4951	3.82	4.05	5.71	5.51	6.14	5.47	5.80	5.15	4.49	4.03	3.66	3.48	57.31
Flamin	527565.3021	296766.6878	3.95	4.39	6.10	6.31	7.13	5.99	6.36	6.30	5.48	4.64	4.31	3.83	64.79
Homest	664918.2229	424260.2199	3.72	4.26	5.65	6.08	6.48	5.47	5.66	5.55	4.54	3.79	3.37	3.37	57.93
TTrail	560324.4884	520916.8078	3.48	3.92	5.52	6.25	6.68	5.35	5.49	5.24	4.44	3.59	3.05	3.14	56.16
MIA	730278.4905	539658.9643	3.63	4.14	5.52	5.84	6.45	5.60	5.72	5.91	4.70	3.88	3.37	3.31	58.08
FTL	762547.3199	642814.7394	3.44	4.10	5.42	5.69	6.10	5.25	5.37	5.67	4.51	3.76	3.22	3.17	55.70
WPBIA	793886.7964	855051.2010	3.39	4.04	5.33	5.67	6.11	4.97	5.35	5.30	4.43	3.52	3.03	3.07	54.20
CPoint	619547.8702	920849.7413	3.39	3.93	4.84	5.87	6.25	5.33	5.71	5.41	4.50	3.84	3.38	3.24	55.68
BGlade	619774.8414	842082.8625	3.52	4.09	5.03	5.97	6.32	5.25	5.64	5.32	4.43	3.83	3.47	3.35	56.21
MHaven	472835.4991	908545.4085	3.30	3.89	5.53	5.84	6.42	5.22	5.59	5.31	4.23	3.57	3.22	3.12	55.23
Okee	554174.6483	1041865.2140	3.41	3.68	5.38	5.45	6.04	4.86	5.26	5.02	4.37	3.85	3.47	3.16	53.94
Stuart	770878.6178	1042729.6690	3.18	3.74	5.05	5.49	5.68	5.00	5.51	5.02	4.52	3.37	3.18	3.06	52.79
Vero	688845.9072	1205856.6020	3.20	3.78	5.25	5.54	5.95	4.84	5.50	5.26	4.16	3.25	2.94	2.98	52.63

Table 45. LECsR Wet Marsh Potential Evapotranspiration Rates (in Inches) by ET Station for 2000 (Source: SFWMM)

ETSTATION	X	Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Lokee			3.71	4.08	5.22	5.94	6.32	5.78	5.74	5.54	4.68	4.20	3.66	3.33	58.19
LaBell	358604.7026	884557.3360	3.31	3.73	4.74	5.55	5.97	5.60	5.76	5.39	4.41	3.99	3.53	3.26	55.23
DevGar	456430.6735	823760.0332	3.39	4.03	5.10	5.80	5.98	5.81	5.69	5.26	4.94	4.18	3.27	3.39	56.82
FtMyer	216753.2486	818638.2761	3.77	4.29	5.31	5.84	6.47	6.05	5.56	5.46	4.46	4.33	3.73	3.59	58.85
Naples	243068.5551	667012.6770	3.80	4.52	5.04	5.51	5.95	5.84	5.47	5.50	4.41	4.61	3.37	3.48	57.50
EverGl	373931.7692	551332.4951	3.95	4.41	5.01	5.74	6.18	5.93	5.12	5.66	4.78	4.42	3.62	3.31	58.12
Flamin	527565.3021	296766.6878	4.31	4.39	5.44	5.85	5.70	5.55	5.71	5.75	4.97	4.43	3.10	3.42	58.63
Homest	664918.2229	424260.2199	3.80	4.21	5.25	5.86	6.12	5.56	5.78	5.45	4.53	4.14	3.73	2.88	57.31
TTrail	560324.4884	520916.8078	3.64	4.02	5.07	5.68	6.41	5.67	5.74	5.38	4.54	3.81	3.42	3.28	56.66
MIA	730278.4905	539658.9643	3.75	4.04	5.16	5.80	5.86	5.59	6.03	5.56	4.62	4.10	3.73	3.30	57.53
FTL	762547.3199	642814.7394	3.62	3.83	4.90	5.62	5.48	5.21	5.90	5.48	4.55	4.24	3.58	2.61	55.03
WPBIA	793886.7964	855051.2010	3.55	3.85	4.88	5.36	5.49	5.25	5.74	5.23	4.31	3.70	3.55	3.02	53.94
CPoint	619547.8702	920849.7413	3.68	4.05	5.24	5.92	6.38	5.83	5.81	5.58	4.77	4.16	3.57	3.25	58.24
BGlade	619774.8414	842082.8625	3.84	4.22	5.37	6.07	6.44	5.80	5.74	5.53	4.73	4.20	3.68	3.37	58.99
MHaven	472835.4991	908545.4085	3.63	3.97	5.05	5.82	6.12	5.70	5.66	5.52	4.54	4.22	3.73	3.37	57.33
Okee	554174.6483	1041865.2140	3.64	3.97	4.83	5.55	6.02	5.46	5.20	5.02	4.24	4.07	3.49	3.33	54.81
Stuart	770878.6178	1042729.6690	3.48	3.63	4.93	5.27	5.37	5.00	5.52	5.04	4.10	3.76	3.40	3.04	52.53
Vero	688845.9072	1205856.6020	3.38	3.80	4.79	5.34	5.55	5.33	5.61	5.12	4.19	3.53	3.42	3.03	53.09

Table 46. LECsR Precipitation (in Inches) by Rain Gauge Station for 1986

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	2.68	0.79	3.72	1.11	0.86	13.15	4.99	9.32	2.54	1.84	1.36	3.24	45.6
S80	2.33	0.92	5.34	0.79	1.32	12.43	5.79	6.21	5.01	2.61	1.08	2.42	46.25
S153	2.62	2.66	9.95	0.88	2.74	6.83	6.29	5.8	4.21	1.29	3.53	3.26	50.06
S46	2.36	1.25	8.45	1.02	7.5	9.05	2.84	8.64	3.32	2.05	2.54	3.34	52.36
CANAL	1.93	1.28	2.56	0.92	1.15	6.67	1.66	5.93	3.45	1.61	3.56	3.49	34.21
WPB	2.76	1.38	7.82	0.91	5.33	9.86	3.07	6.26	3.87	1.46	2.38	3.14	48.24
BELLE	2.34	1.04	7.6	0.97	2.38	11.69	3.71	4.51	7.56	2.36	4.43	4.26	52.85
S41	1.71	1.45	3.42	0.87	0.96	8.62	3.06	5.37	4	2.88	3.82	5.26	41.42
S6	4.73	1.64	9.91	0.7	7.32	9.68	6.9	6.52	4.64	3.37	4.25	2.38	62.04
S39	5.14	1.24	9.32	0.62	3.95	7.9	3.93	4.25	7.64	3.89	5.42	4.4	57.7
G56	2.15	1.35	5.6	0.52	3.39	14.15	4.25	8.02	0.38	4	0.65	3.9	48.36
S7	3.43	2.55	6.49	0.81	2.77	11.93	5.09	3.86	3.78	3.1	2.97	4.37	51.15
S37B	2.26	0.9	7.56	0.36	8.79	11.79	3.02	5.53	1.32	3.6	1.84	5.04	52.01
S140	3.3	0.72	6.87	0.09	6.8	14.79	7.28	10.24	2.66	5.65	1.91	5.03	65.34
LAUD	5.56	1.2	11.06	0.65	4.77	6.74	6.88	6.01	4.26	7.39	4.57	3.73	62.82
S9	4.17	1.04	11.05	0.33	5.7	7.47	5.68	6.69	2.66	4.07	4.93	4.27	58.06
S29	4.45	1.06	10.91	0.73	4.26	13.09	5.89	6.37	3.59	4.1	3.03	6.51	63.99
MIA	5.08	1.26	9.77	0.3	3.75	10.68	5.24	7.11	4.35	5.13	3.91	6.45	63.03
S336	9.73	1.75	9.98	0.23	4	9.73	9.87	8.46	5.05	8.16	4.87	8.82	80.65
TAMI40	5.56	2.02	6.09	0.48	1.5	8.88	10.29	5.61	4.02	6.69	6.12	8.83	66.09
TAMIAIR	3.44	2.01	4.95	0.38	3.07	7.38	8.06	6.06	4.35	3.61	2.38	3.3	48.99
NP203	2.32	1.05	3.7	0.1	2.41	11.14	9.27	4.8	4.86	2.64	1.23	3.21	46.73
S331	2.63	1.27	3.33	0.13	2.03	10.87	7.62	5.09	6.79	3.01	2.66	3.16	48.59
HOMEFS	5.04	1.96	10.84	0.1	1.16	8.86	7.39	5.74	4.7	6.06	4.4	7.08	63.33
S20F	4.9	1.99	9.17	1.28	4.58	5.86	6.71	7.39	2.97	7.39	2.03	6.41	60.68
S18C	5.77	1.24	7.31	0.04	2.08	14.53	4.16	4.37	1.5	7.39	2.08	3.38	53.85

Table 47. LECsR Precipitation (in Inches) by Rain Gauge Station for 1987

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	1.31	1.92	8.18	0.46	3.81	2.75	8.3	4.7	12.58	3.72	4.42	1.37	53.52
S80	0.39	0.37	8.9	0.07	4.53	4.59	5.47	10.17	11.64	3.66	8.6	1.84	60.23
S153	0.63	0.86	5.93	0.47	2.14	7.17	5.46	8.91	9.21	3.83	9.13	2.42	56.16
S46	2.2	0.76	4.06	0.01	2.82	12.02	4.44	6.57	12.06	4.1	4.35	2.43	55.82
CANAL	0.4	1.97	4.36	0.12	4.15	2	1.87	5.22	7.51	4.56	4.32	2.79	39.27
WPB	2.38	0.6	4.32	0.4	5.52	7.58	4.2	5	11.08	5.08	4.69	2.72	53.57
BELLE	2.27	2.42	3.5	0.35	4.46	4.39	6.43	5.59	11.79	7.71	3.7	1.83	54.44
S41	0.82	1.7	5.59	0.26	5.82	3.45	3.57	2.27	8.55	5.58	3.84	1.8	43.25
S6	1.45	2.28	3.71	0.63	5.02	4.84	4.71	3.25	9.96	4.88	4.94	3.98	49.65
S39	1.87	4.51	3.53	1.15	7.86	4.34	4.32	2.83	7.72	6.03	4.23	2.41	50.8
G56	0.52	1.57	5.31	0.59	4.17	2.29	3.05	3.85	12	2.13	3.26	0.4	39.14
S7	1.31	1.56	4.51	1.79	5.2	4.72	3.05	6.83	11.08	4.91	6.77	3.53	55.26
S37B	0.69	0.83	5.75	0.06	3.7	4.24	9.64	5.78	9.38	3.62	4.93	0.81	49.43
S140	2.06	1.19	4.05	0.6	2.23	3.55	4.47	5.68	2.45	3.98	7.29	0.58	38.13
LAUD	1.62	3.54	3.76	0.69	9.96	5.82	6.6	1.48	7.28	5.88	5.55	3.98	56.16
S9	1.17	3.38	3.92	1.08	6.12	2.89	6.89	2.79	8.9	4.04	5.9	1.78	48.86
S29	0.94	1.32	4.49	0.17	5.97	3.63	3.7	3.67	8.17	5.78	11.88	1.44	51.16
MIA	2.49	4.9	4.82	2.62	7.8	3.69	5.38	3.48	6.42	5.93	7.18	3.18	57.89
S336	3.19	3.06	8.63	0.83	9.98	4.14	4.44	4.08	13.77	6.44	11.12	2.51	72.19
TAMI40	1.69	1.44	7.04	1.96	4.24	6.32	4.99	1.02	8.76	5.35	8.5	1.52	52.83
TAMIAIR	2.05	1.64	6.27	0.05	2.25	7.79	4.4	4.12	3.91	3.41	8.26	0.25	44.4
NP203	2.4	1.05	5.43	0.26	3.44	4.5	4.34	0.99	6.39	5.55	8.7	0.28	43.33
S331	2.16	1.14	4.73	0.45	2.67	5.67	6.13	1.36	3.8	7.18	6.53	0.06	41.88
HOMEFS	1.48	1.36	7.18	1.34	3.86	7.75	6.79	4.46	6.89	7.42	9.61	0.41	58.55
S20F	2.95	1.67	6.42	0.83	3.33	4.95	5.78	1.88	6.95	7.87	4.65	0.4	47.68
S18C	2.95	1.38	6.42	0.08	3.7	2.42	6.33	2.17	7.39	6.69	7.82	0.03	47.38

Table 48. LECsR Precipitation (in Inches) by Rain Gauge Station for 1988

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	2.58	0.87	2.49	1.39	8.15	12.31	10.93	8.41	3.14	1.15	1.4	0.07	52.89
S80	2.79	0.59	0.48	2.56	4.03	12.32	10.5	11.99	4.63	2.62	1.48	0.34	54.33
S153	1.36	0.72	0.45	2.28	4.26	11.46	14.95	10.97	2.37	2.5	1.01	0.19	52.52
S46	1.71	0.43	0.35	0.88	6.53	14.63	8.35	17.75	1.29	1.7	0.22	0.01	53.85
CANAL	1.85	0.61	0.29	1.43	4.28	9.33	7.2	16.99	2.55	2.89	1.96	0.04	49.42
WPB	1.96	0.48	0.66	1.02	7.22	13.72	9.35	13.77	1.82	2.47	1.26	0.1	53.83
BELLE	2.03	0.79	0.85	2.25	10.48	14.14	10.23	13.6	4.78	3.64	0.78	0.43	64
S41	2.65	0.94	0.48	1.59	13.83	15.57	10.54	11.9	1.57	5.93	4.76	0.36	70.12
S6	1.99	0.61	0.57	1.37	6.11	10.8	10.49	8.18	3.09	1.81	1.13	0.15	46.3
S39	2.11	1.36	1.97	1.36	6.34	7.73	5.33	8.47	0.95	1.22	1.96	0.6	39.4
G56	1.21	1.69	1.75	1.31	3.69	5.58	6.37	9.42	2.45	1.45	3.09	0.13	38.14
S7	2.01	1.91	1.39	4	5.84	11.15	6.32	12.61	0.91	1.27	1.21	0.47	49.09
S37B	2.12	1.51	1.41	2.42	3.5	6.29	8.06	9.56	1.81	0.81	0.69	0.02	38.2
S140	1.61	0.2	1.92	3.16	3.28	6.04	12.56	6.67	1.46	1.37	1.57	0.02	39.86
LAUD	2	1.9	1.45	1.44	5.89	8.15	7.18	8.23	1.43	1.33	1.5	0.73	41.23
S9	1.35	1.44	0.69	2.39	5.74	7.49	7.87	8.41	2.36	1.35	0.82	0.96	40.87
S29	1.31	1.64	0.72	4.71	3.97	8.61	9.5	11.11	4.18	0.92	2.53	0.26	49.46
MIA	2.3	2.62	1.07	2.78	2.69	9.12	10.24	10.02	3.88	2.9	4.46	1.34	53.42
S336	5.32	3.99	1.64	3.54	8.78	9.09	11.46	12.95	3.64	3.24	3.77	2.88	70.3
TAMI40	3.76	3.06	5	2.36	7.59	9.19	13.09	11.6	1.83	2.79	3.47	2.05	65.79
TAMIAIR	3.01	2.25	1.84	0.57	2.96	4.34	8.81	8.98	2.45	0.12	1.31	0.89	37.53
NP203	2.66	2.78	3.72	0.15	2.92	3.7	11.37	11.74	2.61	0.3	3.31	1.36	46.62
S331	2.09	2.87	2.48	1.28	3.59	3.98	8.94	13.01	1.18	0.79	4.55	0.83	45.59
HOMEFS	3.98	4.18	3.38	1.76	7.05	6.76	8.03	13.21	2.43	1.73	2.42	0.61	55.54
S20F	2.7	3.39	4.41	2.78	5.08	4.12	6.98	10.72	1.55	4.84	3.45	1.35	51.37
S18C	2.25	4.23	2.35	2.55	5.26	3.06	8.41	2.76	1.35	0.42	3.65	1.31	37.6

Table 49. LECsR Precipitation (in Inches) by Rain Gauge Station for 1989

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Sum of STUART	1.23	0.06	0.69	2.8	1.44	9.28	7.8	5.32	4.5	1.59	0.76	0.61	36.08
Sum of S80	0.75	0.13	0.54	3.39	1.17	4.74	9.95	5.61	3.66	3.24	2.44	0.3	35.92
Sum of S153	0.42	0.33	1.55	3.22	1.42	6.63	5.12	9.02	5.38	4.3	3.68	0.74	41.81
Sum of S46	1.25	0.53	0.73	4.12	2.59	5.76	9.31	6.95	4.13	4.08	2.95	0.67	43.07
Sum of CANAL	0.47	0.03	1.18	2.09	5.4	3.49	5.64	6.93	3.69	1.72	1.08	0.24	31.96
Sum of WPB	1.02	0.43	0.72	3.11	2.87	6.88	5.06	6.5	4.94	4.51	2.73	0.81	39.58
Sum of BELLE	1.04	0.36	0.68	4.68	3.51	5.45	11.63	5.74	4.65	2	3.24	0.91	43.89
Sum of S41	0.7	0.27	1.24	2.6	5.68	7.83	6.46	7.11	3.17	3.95	2.31	0.23	41.55
Sum of S6	0.66	0.35	0.95	1.99	1.86	9.37	4.15	10.71	5.58	3.01	1.22	0.69	40.54
Sum of S39	0.75	2.42	2.03	3.86	2.25	6.33	4.23	4.34	2.85	4.08	1.44	0.77	35.35
Sum of G56	0.67	0	1.63	4.24	2.94	6.39	4.92	8.35	2.76	1.46	0.67	1.27	35.3
Sum of S7	1.24	0.21	2.48	1.89	1.91	7.03	3.59	4.53	5.27	1.39	0.76	0.66	30.96
Sum of S37B	0.46	0.02	2.37	2.54	0.68	6.26	8.97	7.93	8.91	4	0.88	1.25	44.27
Sum of S140	0.42	0.8	2.55	2.78	2.03	6.86	3.98	5.21	5.12	1.89	1.06	1.44	34.14
Sum of LAUD	1.56	4.42	2.52	4.53	2.98	6.46	5.16	6.11	3.15	4.49	1.56	0.24	43.18
Sum of S9	0.54	0.82	2.9	3.55	2.63	4.11	4.18	3.79	3.23	4.81	1.36	0.54	32.46
Sum of S29	0.94	0.74	0.85	4.16	2.05	5.29	5.07	6.33	2.41	1.87	1.1	1.79	32.6
Sum of MIA	1.13	0.95	2.7	1.88	2.74	5.85	6.11	7.83	4.57	3.41	1.23	1.84	40.24
Sum of S336	1.21	1.55	3.24	6.42	1.49	6.42	3.54	6.1	4.29	4.29	1.42	1.59	41.56
Sum of TAMI40	1.28	0.61	2.95	5.8	0.95	5.46	3.72	6.91	5	5.38	1.52	2.78	42.36
Sum of TAMIAIR	0.99	0.16	2.29	2.98	1.91	2.69	3.6	7	9.04	3.5	1.15	1.95	37.26
Sum of NP203	0.97	0.05	2.89	2.99	1.86	2.75	3.08	8.94	6.83	2.9	0.9	2.51	36.67
Sum of S331	0.7	0.51	4.25	2.85	1.06	3.77	3.8	6.89	4.26	4.64	0.61	2.23	35.57
Sum of HOMEFS	0.58	0.53	4.2	3.14	3.25	3.12	6.68	8.39	3.52	5.24	1.09	1.87	41.61
Sum of S20F	1.74	0.32	4.07	3.83	4.37	2.85	7.4	6.03	6.32	7.01	0.81	3.11	47.86

Sum of S18C	1.74	0.37	5.87	6.88	1.68	2.07	8.46	7.8	4.99	7.12	0.81	3.11	50.9

Table 50. LECsR Precipitation (in Inches) by Rain Gauge Station for 1990

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	2.17	3.75	0.7	1.9	6.01	5.98	6.72	11.02	4	3.45	0.43	0.42	46.55
S80	0.07	0.95	1.05	4.61	4.59	5.79	5.51	8.1	3.51	3.8	1.15	0.63	39.76
S153	0.18	0.82	2.34	4.31	7.32	4.88	8.59	6.76	3.72	3.22	1.04	0.81	43.99
S46	0.54	1.05	3.74	1.87	10.75	3.92	9.08	11.42	5.78	4.88	2.72	0.25	56
CANAL	0	0.39	0.8	1.76	4.6	2.46	3.22	7.22	4.02	2.71	0.72	0.52	28.42
WPB	0.45	1.04	1.9	4.25	6.46	5.48	6.89	12.63	4.49	5.34	2.75	0.69	52.37
BELLE	0.47	0.74	3.3	3.84	7.63	8.24	9.19	13.97	7.03	3.7	1.76	0.71	60.58
S41	0.87	0.24	2.68	3.29	5.86	4.45	8.4	7.15	5.89	3.03	0.95	0.78	43.59
S6	0.38	1.09	2.2	6.58	7.42	6.23	4.59	10.55	3.68	4.67	1.76	1.14	50.29
S39	1.08	0.6	2.89	6.45	7.24	4.53	7.04	3.79	5.27	3.37	0.77	1.79	44.82
G56	1.07	0.8	1.75	0.6	5.88	6.19	6.32	6.88	2.96	2.06	0.99	0.18	35.68
S7	0.9	2.1	3.2	2.05	5.03	4.62	9.35	6.24	2.74	4.48	0.61	0.94	42.26
S37B	0.22	3.21	2.24	1.6	3.61	8	7.28	9.93	1.28	3.41	0.44	0.98	42.2
S140	0.37	3.32	2.19	0.92	5.17	4.11	6.24	7.36	2.21	3.99	0.45	1.24	37.57
LAUD	0.73	0.86	4.56	6.57	9.14	7.01	10.63	5.43	7.39	4.89	0.64	2.1	59.95
S9	0.65	0.93	3.27	3.9	9.41	6.97	9.43	7.21	5.17	5.5	0.52	2.44	55.4
S29	2.04	2.54	2.22	2.53	8.03	6.92	9.04	7.25	4.96	3.03	0.46	2.03	51.05
MIA	0.86	0.9	2.06	4.42	8.3	6.98	10.02	11.93	6.88	4.46	1.76	2.96	61.53
S336	1.42	1.24	1.81	7.08	6.79	6.72	17	8.27	6.24	2.91	0.86	2.6	62.94
TAMI40	1.79	1.46	1.8	3.01	7.38	4.61	9.67	7.31	8.89	4.05	1.08	2.22	53.27
TAMIAIR	2.27	2.62	1.1	2.18	6.46	5.87	8.71	7.03	3.45	4.1	0.37	1.03	45.19
NP203	0.82	4.7	1.04	2.01	2.91	4.6	5.31	3.63	4.47	3.35	0.46	0.24	33.54
S331	1.83	1.91	0.93	1.54	4.46	4.61	5.42	8.16	6.19	6.66	0.57	0.33	42.61
HOMEFS	2.91	1.18	2.28	2.67	4.75	3.15	4.22	10.26	9.6	5.96	2.57	3.37	52.92
S20F	2.45	2.21	2.66	0.66	3.77	4.98	10.22	8.35	15.01	3.58	1.99	0.66	56.54
S18C	2.45	2.31	1.31	0.66	3.77	4.26	10.22	8.35	15.01	3.58	1.99	0.51	54.42

Table 51. LECsR Precipitation (in Inches) by Rain Gauge Station for 1991

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	2.22	1.03	1.2	4.79	9.25	11.06	14.14	7.25	6.53	5.73	1.95	0.96	66.11
S80	2.31	0.97	1.95	3.3	14.41	8.26	10.64	7.9	3.07	4.35	0.59	0.63	58.38
S153	1.87	1.31	1.14	3.5	3.92	8.8	7.77	4.04	7.08	7.41	1.15	0.4	48.39
S46	2.53	0.74	2.57	4.34	10.12	10.32	5.66	6.98	10.75	8.88	1.17	0.8	64.86
CANAL	2.78	0.97	2.78	4.36	10.42	8.39	3.49	5.32	7.07	7.37	0.8	1.09	54.84
WPB	2.28	1.88	1.45	3.88	5.71	12.24	6.56	10.03	7.21	8.81	1.39	0.91	62.35
BELLE	2.59	2.97	3.42	4.54	7.09	12.41	7.03	8.93	10.44	13.22	0.75	0.91	74.3
S41	1.06	2.21	2.6	3.91	5.44	10.64	3.7	4.56	5.92	13.57	1.04	0.75	55.4
S6	1.43	1.77	2.3	4.5	2.95	7.45	7.51	8.31	8.2	20.57	1.57	0.27	66.83
S39	2.1	1.62	2.15	2.79	3.47	7.41	5.67	4.23	5.6	18.08	4.58	0.39	58.09
G56	7.99	2.84	0.99	4.4	8.17	7.84	9.91	3.3	4.96	4.13	3.61	0.13	58.27
S7	2.89	3.06	0.81	6.74	6.12	9.63	7.84	6.18	4.48	7.1	2.43	0.36	57.64
S37B	8.72	3.1	1.14	4.51	7.66	7.21	8.52	5.35	3.98	2.84	4.87	0.11	58.01
S140	8.83	2.18	1.16	2.8	5.16	11.8	6.03	3.88	4.22	1.09	2.27	0.5	49.92
LAUD	4.39	2.71	1.61	5.57	6.36	11.28	7.2	5.66	5.59	16.54	3.78	0.49	71.18
S9	3.98	5.88	1.67	7.68	4.02	13.29	8.37	5.6	6.74	8.08	3.09	0.43	68.83
S29	8.92	5.22	1.13	5.33	6.89	12.96	6.19	5.54	4.61	4.48	4.86	1.21	67.34
MIA	5.09	6.83	1.78	6.06	4	11.42	5.22	6.48	6.31	10.48	5.52	0.54	69.73
S336	8.75	3.55	3.25	5.99	6.93	6.85	7.1	7.21	6.99	5.62	3.71	0.61	66.56
TAMI40	10.88	4.25	3.34	9.02	8.91	9.02	6.47	7.55	5.82	7.58	2.74	3.93	79.51
TAMIAIR	8.15	1.46	2.46	4.78	4.84	7.9	11.9	3.21	5.8	3.45	2.29	0.52	56.76
NP203	5.48	1.98	4.46	6.72	3.25	4.94	8.84	7.04	4.92	3.08	2.47	0.69	53.87
S331	5.64	3.52	3.27	4.92	3.25	8.49	9.12	5.75	5.66	4.9	3.38	0.6	58.5
HOMEFS	7.34	6.24	4.97	5.85	8.76	10.13	7.06	6.12	7.73	7.87	3.09	2.37	77.53
S20F	6.83	5.83	6.37	7.92	7.68	10.22	7.17	7.34	6.92	4.56	0.87	1.76	73.47
S18C	5.6	5.83	4.75	7.12	7.68	7.24	5.44	11.31	7.15	8.74	1.82	1.22	73.9

Table 52. LECsR Precipitation (in Inches) by Rain Gauge Station for 1992

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	0.91	1.75	1.96	4	0.14	17.32	1.07	12.53	4.85	3.33	5.47	0.13	53.46
S80	1.19	1.64	2.34	2.22	0.61	17.1	2.1	6.43	2.56	1.61	3.1	0.73	41.63
S153	2.43	1.19	1.79	2.31	0.32	18.45	2.54	9.02	2.17	1.33	6.37	0.34	48.26
S46	2.87	1.89	3.13	2.58	0.86	25.08	2.2	18.4	4.22	1.79	4.89	0.15	68.06
CANAL	1.57	1.58	1.23	2.28	0.94	21.2	3.13	9.67	5.34	2.05	4.87	0.05	53.91
WPB	4.09	1.3	3.43	2.97	0.82	18.98	2.69	12.58	3.22	5.12	5.64	0.82	61.66
BELLE	3.04	1.48	2.48	1.65	0.55	27.92	1.92	12.81	3.37	2.85	6.27	0.1	64.44
S41	3.18	1.42	3.77	0.87	0.31	20.63	1.9	9.68	1.91	3.2	2.66	0.16	49.69
S6	3.92	1.86	2.95	2.53	0.55	9.16	2.8	9.81	3.88	2.69	12.58	1.71	54.44
S39	6.22	2.27	1.97	2.86	0.37	12.33	3.38	6.89	2.68	2.7	8.95	0.29	50.91
G56	1.36	4.24	1.62	3.38	0.77	26.04	3.73	6.35	3.12	0.29	2.62	0.18	53.7
S7	2.43	1.81	1.53	2.92	0.68	15.65	2.09	9.03	4.66	0.56	6.69	0.61	48.66
S37B	0.7	3.82	1.16	3.69	2.86	18.04	1.78	10.59	4.72	1.65	5.35	0.66	55.02
S140	0.95	3.35	0.8	2.64	2.53	11.53	2.86	9.13	3.11	2.21	6.06	0.91	46.08
LAUD	3.82	3.31	2.31	3.55	0.85	22.44	2.4	6.54	3.94	2.45	6.34	1.73	59.68
S9	5.31	4.18	2.01	3.34	0.97	20.35	3.9	6.23	2.78	2.02	8.58	0.66	60.33
S29	1.9	4.03	1.67	5.67	1.42	15.57	3.51	9.07	4.3	1.91	8.88	0.59	58.52
MIA	5.66	4.84	2.3	3.75	0.93	14.2	1.92	6.4	2.77	1.57	10.72	2.2	57.26
S336	3.25	4.65	1.25	4.01	0.84	16.78	0.94	4.78	2.96	2.4	17.96	0.29	60.11
TAMI40	1.96	3.59	2.5	2.86	1.68	15.89	2.32	7.25	5.98	2.81	10.22	1.37	58.43
TAMIAIR	1.26	2.78	2.11	3.92	0.64	14.67	3.43	11.88	10.42	2.37	4.04	0.53	58.05
NP203	1.98	3.53	2.83	4.17	1.77	12.38	3.28	11.74	14.55	0.8	4.42	1.92	63.37
S331	3.08	6.05	2.72	5.75	2.84	16.76	5.8	6.52	7.54	2.27	2.51	0.75	62.59
HOMEFS	1.03	7.04	4.18	5.16	1.94	9.02	3.86	11.07	11.33	2.26	9.11	0.76	66.76
S20F	1.15	2.7	4.16	2.98	2.14	16.8	3.95	15.21	6.29	6.26	10.71	0.53	72.88
S18C	1.96	4.82	1.5	3.11	2.42	14.15	4.07	15.7	11.45	4.05	13.93	1.25	78.41

Table 53. LECsR Precipitation (in Inches) by Rain Gauge Station for 1993

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	4.24	0.64	2.04	5.7	5.47	5.75	2.66	7.04	7.28	12.79	0.49	0.97	55.07
S80	4.89	0.38	1.69	2.78	3.85	3.56	4.36	4.52	6.92	9.76	0.03	0.88	43.62
S153	4.7	2.07	4.64	3	4.89	7	5.11	6.02	6.67	8.02	0.67	0.43	53.22
S46	5.53	0.61	3.55	3.96	5.64	11.29	5.16	5.42	4.43	9.21	0.66	0.28	55.74
CANAL	5.18	1.24	1.64	1.21	4.1	5.55	5.9	5.32	3.35	6.19	0.34	0.64	40.66
WPB	6.21	0.65	3.2	5.39	4.18	15.95	5.39	5.89	5.74	10.35	0.86	0.5	64.31
BELLE	9.77	1.08	1.85	2.4	7.22	5.37	9.87	6.08	5.09	10.34	3.16	0.29	62.52
S41	7.89	0.42	1.93	3.07	4.79	3.67	4.51	4.97	3.98	5.87	0.49	0.24	41.83
S6	5.99	1.79	5.43	3.59	5.34	4.94	7.29	5.14	8.82	8.32	5.12	0.53	62.3
S39	8.1	2.36	3.16	3.67	1.19	2.75	6.28	5.84	5.02	7.96	2.21	0.27	48.81
G56	6.6	1.21	2.6	3.77	4.14	4.84	9.27	4.09	6.3	6.56	0.6	0.61	50.59
S7	4.81	0.79	3.72	2.97	5.88	5.84	3.67	4.82	3.86	6.94	0.75	0.57	44.62
S37B	6.91	1.63	4.33	2.86	2.57	11.75	6.53	7.83	9.08	6.64	0.99	0.64	61.76
S140	4.79	1.68	2.61	2.37	2.72	4.82	3.76	5.17	3.92	6.12	1.59	0.68	40.23
LAUD	9.19	2	5.03	1.76	2.88	3.9	9.76	7.59	6.96	12.98	1.4	0.89	64.34
S9	5.2	0.97	6.11	2.27	1.67	2.6	9.45	4.34	7	14.48	1.86	0.59	56.54
S29	4.42	1.49	2.48	5.56	1.86	6.1	3	6.71	3.03	9.45	1.74	0.76	46.6
MIA	7.33	2.23	5.24	2.36	1.18	4.65	5.69	6.21	5.53	8.92	2.64	1.17	53.15
S336	5.57	2.32	7.69	2.98	1.33	2.77	3.32	4.75	4.72	5.03	2.33	0.67	43.48
TAMI40	10.88	2.26	10.09	2.54	1.79	3.05	5.16	4.98	6.72	10.86	4.1	0.89	63.32
TAMIAIR	10.05	1.03	3.02	2.46	3.94	6.5	3.17	5.71	6.15	7.58	1.89	0.77	52.27
NP203	7.54	2.81	4.05	2.36	10.27	4.24	2.54	6.56	5.74	4.78	2.66	0.37	53.92
S331	6.4	2.56	3.26	1.6	2.76	5.34	2.56	3.67	3.55	2.74	2.24	0.4	37.08
HOMEFS	14.62	3.9	8.54	2.56	3.52	4.91	3.82	5.24	8.3	12.13	5.24	0.73	73.51
S20F	11.44	2.27	6.15	3.22	6.49	5.92	2.77	4.45	10.54	17.95	9.16	3.28	83.64
S18C	9.51	3.29	8.52	3.62	6.84	4.68	4.82	5.25	6.48	11.37	4.12	0.41	68.91

Table 54. LECsR Precipitation (in Inches) by Rain Gauge Station for 1994

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	2.44	2.78	2.13	1.49	3.31	10.02	6.19	5.06	9.4	8.4	7.97	4.86	64.05
S80	1.18	2.07	3.27	1.6	4.6	6.2	5.14	6.58	8.87	8.58	2.81	3.69	54.59
S153	2.27	5.14	1.27	4.77	4.81	3.51	3.74	12.58	9.11	7.75	8.81	4.04	67.8
S46	1.98	7.25	1.1	6.68	5.61	7.8	7.05	13.47	11.74	9.22	6.37	3.69	81.96
CANAL	2.43	5.25	0.69	2.76	3.98	4	3.88	6.65	12.73	9.25	7.8	3.33	62.75
WPB	3.57	10.63	1.03	6.11	3.79	8.12	6.21	14.93	9.79	9.51	6.94	5.33	85.96
BELLE	2.94	6.85	1.43	3.41	5.14	6.57	5.72	8.65	9.86	6.7	8.7	5.29	71.26
S41	2.14	7.14	1.83	5.76	7.72	2.88	5.2	8.38	9.64	5.83	11.59	3.46	71.57
S6	4.77	5.47	1.68	4.7	4.79	4.33	3.96	14.42	12.63	7.27	7.65	4.55	76.22
S39	3.16	3.76	2.72	4	5.96	3.54	2.29	8.03	8.33	5.54	9.16	6.05	62.54
G56	3.32	2.53	3.2	5.4	1.97	10.3	4.75	8.37	12.19	9.45	10.27	6.7	78.45
S7	2.58	3.63	1.81	4.52	3.55	7.69	6.67	8.74	9.91	5.19	10.23	5.39	69.91
S37B	4.35	3.36	7.11	2.83	2.67	5.13	7.04	8.33	12.24	4.35	8.17	16.86	82.44
S140	4.09	7.75	3.64	1.96	3.57	5.42	4.69	7.66	10.21	4.55	9.23	13.11	75.88
LAUD	4.05	4.14	1.7	8.63	5.27	7.49	2.7	10.88	14.73	2.56	13.3	6.76	82.21
S9	3.84	2.95	1.64	3.66	5.66	5.28	5.01	13.54	10.56	3.23	12.43	7.3	75.1
S29	2.1	3.5	1.82	0.74	3.27	5.85	6.94	8.64	10.83	3.94	12.12	4.45	64.2
MIA	3.32	3.84	1.77	4.44	3.49	3.43	3.33	11.16	5.88	3.88	9.92	8.59	63.05
S336	2.09	2.22	4.42	2.21	1.95	12.8	2.36	6.51	8.13	2.44	7.76	6.91	59.8
TAMI40	6.11	3.47	2.36	6	3.7	11.38	4.85	9.75	11.28	5.97	9.41	11.83	86.11
TAMIAIR	5.26	3.21	2.88	1.8	3.88	9.2	8.73	10.25	5.35	11.8	5.6	7.34	75.3
NP203	5.37	2.8	3.22	4.72	2.2	7.14	4.83	6.29	9.24	4.76	5.84	5.22	61.63
S331	2.66	2.34	1.63	4.29	3.86	5	6.62	6.88	10.86	3.19	4.03	5.39	56.75
HOMEFS	3.12	3.05	2.12	4.57	3.97	8.58	6.19	9.62	8.21	6.63	8.64	6.16	70.86
S20F	5.31	6.81	4.84	6.89	4.73	9.62	8.56	11.48	13.8	9.35	10.17	8.37	99.93
S18C	4.14	5.99	2.05	8.95	3.73	6.64	10.57	12.25	13	7.38	11.69	8.93	95.32

Table 55. LECsR Precipitation (in Inches) by Rain Gauge Station for 1995

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	3.37	0.66	1.57	1.9	7.22	17.13	7.62	9.2	8.46	12.16	0.18	0.89	70.36
S80	2.98	1.11	0.92	1.99	2.17	19.9	7.01	7.24	5.66	8.3	0.27	0.69	58.24
S153	3.38	1.61	2.25	1.98	3.84	19.91	5.97	14.24	9.82	10.85	1.97	0.89	76.71
S46	1.98	0.65	1.7	6.31	4.01	16.38	5.95	8.7	7.33	10.71	1.31	0.7	65.73
CANAL	1.62	0.34	2	3.44	4.7	12.68	4.79	11.28	8.75	11.53	0.34	0.82	62.29
WPB	2.71	0.88	2.08	4.97	6.13	18.97	5.95	11.72	7.97	13.96	1.07	0.84	77.25
BELLE	2.37	1.25	2.06	2.91	5.28	14.54	13.23	11.89	12.61	12.88	0.75	0.98	80.75
S41	1.9	1.28	1.37	3.29	5.38	16.7	7.32	10.65	12.3	9.29	0.96	0.71	71.15
S6	2.23	1.77	3.3	4.74	2.56	17.91	5.21	14.45	9.11	10.44	3.22	0.6	75.54
S39	3.99	2.39	2.07	4.04	1.57	25.8	5.21	15.63	7.54	9.5	2.11	1.27	81.12
G56	3.52	2.02	1.34	1.86	6.3	8.75	6.6	10.89	5.51	7.6	0.8	0.47	55.66
S7	2.78	1.39	2.51	2.64	1.89	12.58	4.85	11.49	4.61	7.7	1.45	1.29	55.18
S37B	2.88	2.25	2.12	3.41	3.79	9.96	13.04	12.82	6.95	7.53	0.29	0.99	66.03
S140	2.4	1.78	1.76	2.78	2.79	8.36	7.29	14.44	5.36	8.86	0.6	1.16	57.58
LAUD	3.81	2.03	3.07	3.17	1.98	15.88	8.88	16.78	12.72	10.65	1.56	0.85	81.38
S9	3.5	4.89	3.17	3.3	2.94	12.09	11.15	14.38	6.33	13.47	0.97	1.46	77.65
S29	3.63	3.87	5.7	1.55	1.47	7.21	10.47	10.99	4.78	8.29	0.97	2.08	61.01
MIA	3.91	4.41	3.91	3.25	1.69	10.77	9.17	15.13	5.07	14.41	1.17	2.24	75.13
S336	2.7	1.24	1.64	2.71	3.89	6.19	7.27	17.33	3.31	12.26	1.18	1.75	61.47
TAMI40	3.58	1.03	2.53	3.45	1.2	7.29	7.83	20.11	7.79	13.42	2.04	2.33	72.6
TAMIAIR	2.01	2.92	2.59	1.54	2.2	9.94	6.33	10.4	8.32	9.23	0.81	0.83	57.12
NP203	2.46	1.21	5.79	1.65	4.42	4.67	12.07	8.04	3.07	12.86	1.51	0.47	58.22
S331	1.43	1.58	5.92	1.09	3	2.91	3.85	9.65	3.22	11.5	0.74	0.42	45.31
HOMEFS	2.61	1.55	3.04	3.88	0.71	8.43	8.84	13.28	4.76	21.81	1.48	1.57	71.96
S20F	2.56	2.25	3.48	3.49	2.27	6.15	3.47	14.71	3.81	24.48	0.24	1.2	68.11
S18C	2.98	1.99	3.92	8.44	2.65	10.11	5.66	22.86	6.75	19.55	0.73	1.2	86.84

Table 56. LECsR Precipitation (in Inches) by Rain Gauge Station for 1996

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	1.08	0.68	2.44	2.42	10.39	8.45	3.21	7.17	6.29	8.03	0.4	0.77	51.33
S80	1.22	0.23	1.78	4	5.63	10.04	3.88	6.7	3.06	6.47	0	1.17	44.18
S153	1.75	0.23	1.2	1.91	8.26	8.16	3.41	7.98	5.14	9.96	0.41	0.67	49.08
S46	1.41	0.68	1.38	2.03	10.58	16.64	3.04	8.66	8.85	8.42	0.23	0.31	62.23
CANAL	1.14	0.32	1.69	1.91	4.24	12.21	1.88	5.49	6.34	11.72	0.31	1.17	48.42
WPB	1.57	1.53	1.75	3.82	9.28	15	4.57	5.39	7.93	8.8	0.56	0.53	60.73
BELLE	2.15	1.96	1.6	2.08	5.71	12.06	2.52	8.25	7.46	6.91	0.2	1.06	51.96
S41	1.29	0.64	1.38	1.27	5.72	15.76	3.19	3.76	7.01	5.62	0.32	0.44	46.4
S6	1.74	2.14	1.23	2.87	8.49	11.88	3.8	7.38	8.69	11.11	1.01	0.93	61.27
S39	2.33	0.4	2.53	4.4	9.49	15.6	3.3	7	7.52	11.24	1.07	1.66	66.54
G56	0.78	0.61	3.11	2.48	5.04	10.52	4.92	5.63	3.23	6.29	0.12	0.94	43.67
S7	1.14	0.24	2.65	2.58	9.02	6.32	1.33	4.96	5.41	7.9	0.63	0.35	42.53
S37B	0.85	0.56	2.84	1.89	7.71	8.46	6.95	4.31	3.98	6.84	0.56	0.51	45.46
S140	2.25	0.45	3.77	1.89	8.12	6.7	3.68	7.9	7.55	5.79	2.07	0.53	50.7
LAUD	2.65	0.68	2.91	2.9	10.95	15.79	1.93	4.37	7.8	13.41	1.48	2.85	67.72
S9	1.21	0.29	3.61	2.96	9.9	12.27	2.04	7.75	7.23	10.64	2.6	1.87	62.37
S29	1.88	0.75	2.1	2.09	5.64	15.8	2.19	9.23	6.7	6.64	1.59	1.04	55.65
MIA	1.85	0.46	4.01	4.35	7.44	9.25	1.33	5	7.48	7.11	1.38	3.51	53.17
S336	2.91	0.45	3.98	1.54	6.6	8.32	1.94	3.7	3.63	5.86	2.6	3.83	45.36
TAMI40	1.58	0.79	6.32	1.29	9.38	8.43	3.14	4.73	8.12	7.29	2.18	1.53	54.78
TAMIAIR	1.78	0.44	6.67	1.58	8.7	9.9	3.3	9.27	3.39	4.31	0.95	0.36	50.65
NP203	2.05	0.26	6.11	1.15	7.42	5.35	5.29	2.97	2.04	4.08	1.87	1.74	40.33
S331	1.93	0.37	5.65	1.66	3.79	6.07	2.61	3.19	2.09	4.38	1.48	2.68	35.9
HOMEFS	1.08	1.35	10.91	1.43	8.66	6.77	5.47	6.87	5.98	6.85	1.59	1.35	58.31
S20F	1.02	0.34	11.84	2.6	8.15	4.05	4.42	2.62	3.84	6.91	1.63	2.44	49.86
S18C	1.13	0.57	13.56	1.79	10.86	5.03	5.48	5.13	4.36	6.56	2.77	1.89	59.13

Table 57. LECsR Precipitation (in Inches) by Rain Gauge Station for 1997

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	1.51	2.38	3.39	5.82	4.53	9.41	9.54	6.93	7.19	0.36	4.13	6.51	61.7
S80	1.06	2.85	2.34	3.27	5.78	14.83	5.38	3.99	6.78	0.24	3.06	7	56.58
S153	1.35	0.86	3.25	4.89	3.62	13.54	5.53	6.19	10.76	0.71	4.05	5.23	59.98
S46	1.16	1.76	3.6	4.06	3.83	12.66	4.5	8.11	10.69	1.43	2.5	6.47	60.77
CANAL	3.96	0.86	1.7	1.61	2.83	18.89	8.17	8.62	8.1	2.18	0.94	6.85	64.71
WPB	1.72	2.51	2.21	4.8	6.92	13.66	8.58	9.97	13.19	1.12	1.57	6.07	72.32
BELLE	4.16	1.43	1.63	1.7	4.43	19.23	9.28	8.99	14.18	1.28	2.83	7.45	76.59
S41	6.57	1.43	0.88	1.74	4.11	14.94	3.71	5.95	8.23	1.7	2.16	8.12	59.54
S6	2.35	1.97	2.71	6.58	9.2	16.96	4.94	4.42	12.9	1.57	3.04	5.56	72.2
S39	2.98	2.66	2.29	4.51	4.48	16.24	3.74	8.27	14.04	2.38	2.47	6.14	70.2
G56	1.79	1.35	2.67	5.19	4.69	9.43	10.78	11.27	8.63	0.72	4.02	6.24	66.78
S7	2.18	0.98	1.22	6.04	3.16	14.9	5.87	3.16	7.35	0.68	3.07	5.38	53.99
S37B	1.98	0.34	2.06	3.38	5.33	12.55	7.49	7.14	8.08	0.91	3.02	4.83	57.11
S140	2.53	1.16	2.37	2.36	2.75	10.79	6.66	9.69	6	1.6	2.93	5	53.84
LAUD	8.36	6.47	4.22	6.73	5.61	13.02	4.66	6.75	11.04	3.28	2.82	5.13	78.09
S9	6.03	4.32	3.31	6.2	5.14	10.69	4	9.06	12.91	1.81	3.16	4.15	70.78
S29	3.2	1.95	2.92	4.02	3.13	14.39	3.57	6.95	5.21	2.17	4.09	4.74	56.34
MIA	6.79	2.65	3.68	4.91	3.85	11.2	5.24	8.99	11.39	1.66	2.14	5.2	67.7
S336	3.36	2.38	3.58	4.25	5.25	13.13	4.28	9.43	6.13	0.54	2.43	8.13	62.89
TAMI40	4.23	6.18	3.45	5.63	3.29	12.82	4.34	11.77	7.69	1.01	3.94	5.58	69.93
TAMIAIR	1.28	2.59	2.42	3.83	5.34	8.67	7.28	4.82	5.28	0.68	3.16	6.52	51.87
NP203	2.19	1.62	2.94	3.95	3.53	7.95	5.53	5.09	4.41	1.29	2.05	5.69	46.24
S331	1.71	0.62	2.74	3.87	3.57	4.99	2.95	3.47	6.25	0.61	1.66	3.66	36.1
HOMEFS	2.46	3.27	3.52	6.83	4.2	11.34	4.29	12.31	10.24	2.58	2.41	5.83	69.28
S20F	3.85	2.58	2.46	5.54	3.34	6.9	2.87	8.41	8.09	1.54	5.44	5.45	56.47
S18C	3.39	2.58	2.46	5.54	3.34	6.9	2.87	8.41	8.09	0.64	2.81	5.96	52.99

LECsR Precipitation (in Inches) by Rain Gauge Station for 1998

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	1.31	6.46	6.6	0.31	3.48	1.7	7.89	6.2	12.19	5.8	6.08	0.9	58.92
S80	2.21	6.65	6.06	0.31	2.6	3.82	9.89	8.98	9.69	3.16	2.39	0.36	56.12
S153	1.17	5.72	5.33	0.58	3.56	3.52	6.76	10.08	11.79	3.07	5.67	1.98	59.23
S46	1.16	5.1	5.43	0.19	2.7	3.37	5.28	8.57	9.96	2.24	4.15	0.74	48.89
CANAL	2.2	5.57	5.37	0.04	2.73	3.48	3.11	8.33	11.26	3.72	6.46	0.91	53.18
WPB	1.23	3.6	5.74	0.44	3.18	4.34	4.98	7.89	8.37	3.41	3.95	1.41	48.54
BELLE	2.7	4.3	4.96	0.18	5.2	3.18	5.86	8.81	12	3.68	5.67	0.57	57.11
S41	2.24	5.5	5.28	0.15	5.59	4.34	2.87	4.63	9.61	2.62	5.73	1.22	49.78
S6	1.2	3.69	6.11	0.8	3.03	5.36	3.87	9.61	13.84	6.2	6.92	2.16	62.79
S39	1.51	6.91	4.16	0.39	4.21	2.63	3.48	3.1	14.54	2.82	7.21	1.94	52.9
G56	0.95	5.08	4.18	0.66	2.18	3.91	6.09	9.68	9.35	4.06	8.21	1.62	55.97
S7	1.31	4.36	3.23	1.35	1.95	1.88	7.97	7.75	10.04	2.31	4.27	1.61	48.03
S37B	1.2	7.14	5.59	1.15	3.35	4.94	7.3	7.83	6.7	0.84	6.65	1.22	53.91
S140	1.58	5.26	5.4	3.14	2.51	1.23	6.97	3.78	7.6	2.1	7.52	1.73	48.82
LAUD	4.9	4.97	4.14	0.75	5.23	3.9	8.67	4.71	15.35	2.75	9.07	2.82	67.26
S9	5.78	5.23	4.73	0.71	2.94	3.55	6.82	5.57	12.55	2.92	8.16	2.44	61.4
S29	2.5	5.62	6.43	1.23	3.49	3.13	9.81	3.98	13.71	2.94	7.5	3.3	63.64
MIA	3.25	4.14	7.78	1.13	1.78	2.29	6.14	3.07	13.97	2.77	12.46	2.24	61.02
S336	7.49	9.8	7.76	1.59	1.51	2.45	6.72	2.78	13.62	0.95	15.33	4.4	74.4
TAMI40	10.23	6.93	4.54	1.08	2.11	1.8	7.47	5.32	12.59	1.5	8.24	3.44	65.25
TAMIAIR	1.38	3.43	3.72	0.4	1.66	2.15	4.56	8.31	11.18	2.19	11.55	0.9	51.43
NP203	1.71	4.49	4.19	0.63	1.69	3.04	5.01	5.07	6.85	1.24	7.36	0.6	41.88
S331	2.45	7.95	4.8	1.21	0.65	3.37	3.91	5.43	8.05	0.81	11.12	1.72	51.47
HOMEFS	6.11	6.63	5.12	1.88	2.96	4.29	5.18	5.79	11.42	4.06	8.4	1.55	63.39
S20F	5.11	10.13	5.99	4.06	5.32	4.88	6.05	10.24	12.2	2.79	7.4	2.33	76.5
S18C	4.45	9.61	6.76	1.17	4.41	3.85	5.28	10.44	16.37	2.07	7.29	2.33	74.03

LECsR Precipitation (in Inches) by Rain Gauge Station for 1999

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	3.26	4.52	0.46	2.5	6.68	14.89	7.17	7.8	11.09	16.9	1	0.88	77.15
S80	4.21	0.43	0.37	1.35	6.24	13.88	5.5	9.56	12.32	13.66	3.89	0.72	72.13
S153	3.03	0.48	0.48	3.35	5.08	20.58	5.39	12.54	6.08	13.27	0.77	1.53	72.58
S46	3	0.34	0.32	1.35	5.42	9.99	6.65	10.72	8.9	13.71	0.67	0.5	61.57
CANAL	1.79	0.27	0.56	0.37	4.27	9.48	8.73	7.94	7.3	10.91	1.55	1.87	55.04
WPB	3.58	0.58	0.95	1.6	5.85	9.93	3.45	7.62	5.71	9.09	0.96	1.32	50.64
BELLE	3.95	0.47	0.67	0.48	3.78	12.94	5.66	8.32	9.76	14.22	1.78	1	63.03
S41	3.42	0.23	0.38	0.33	2.4	8.67	1.52	8.16	6.19	12.5	1.77	1.01	46.58
S6	3.18	0.17	0.4	1.26	4.42	12.73	3.55	11.75	7.78	14.17	1.63	2.41	63.45
S39	2.84	0.5	0.3	0.47	2.4	12.51	5.87	6.18	10.14	12.37	0.76	1.99	56.33
G56	3.04	1.88	0.43	1.41	2.9	10.3	7.05	7.18	11.96	11.37	1.25	0.18	58.95
S7	1.95	0.28	0.32	2.31	4.42	9.03	4.24	6.56	7.93	9.18	1.49	0.84	48.55
S37B	2.75	1.55	0.41	1.12	4.93	12	5.94	5.48	9.83	10.8	1.23	0.58	56.62
S140	1.98	1.63	0.37	1.4	1.73	10.29	5.23	5.11	7.34	10.02	1.45	0.44	46.99
LAUD	3.74	0.82	0.6	1.16	3.03	18.9	4.39	10.8	7.65	16.6	2.99	1.68	72.36
S9	3.09	0.78	0.38	1.49	3.57	16.83	3.81	15.09	2.97	9.22	2.76	1.19	61.18
S29	2.87	2.49	0.53	0.92	2.55	16.23	2.63	6.28	10.59	7.84	2.72	0.77	56.42
MIA	2.66	1.31	0.8	1.17	1.45	10.87	2.64	8.46	6.32	10.71	2.66	0.87	49.92
S336	5.15	0.9	0.37	1.96	1.78	11.99	3.47	12.17	8.79	20.75	2.73	2.32	72.38
TAMI40	6.58	1.89	0.67	0.81	2.37	14.97	2.35	9.23	7.25	16.22	2.34	1.65	66.33
TAMIAIR	1.81	0.59	0.17	0.81	5.23	10.85	6.92	4.93	8.45	7.02	1.34	0.66	48.78
NP203	1.36	0.44	0.87	0.71	1.93	11.51	2.96	5.62	7.92	8.26	1.14	0.56	43.28
S331	1.76	1.2	0.3	0.67	3.34	10	5.34	6.96	4.09	4.64	0.67	0.55	39.52
HOMEFS	9.24	0.48	0.37	0.96	3.32	12.68	5.94	10.06	11.17	11.54	0.53	2.6	68.89
S20F	2.74	2.04	0.92	0.95	3.73	14.77	2.92	12.31	13.06	15.89	0.9	2.02	72.25
S18C	2.74	2.04	0.92	0.95	3.73	14.77	2.92	12.31	13.06	15.89	0.9	2.02	72.25

Table 58. LECsR Precipitation (in Inches) by Rain Gauge Station for 2000

Rain Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STUART	0.59	0.79	0.62	8	1.32	9.9	6.37	5.99	11	5.17	0.09	0.7	50.54
S80	0.47	1	0.54	6.53	1.67	9.35	6.28	8.15	5	6.05	0.28	2.23	47.55
S153	0.31	2	1.32	6.01	0.59	4.38	5.5	7.04	2.5	8.46	0.06	1.29	39.46
S46	0.32	0.6	0.99	2.8	1.33	3.38	8.46	6.38	5.29	10.41	0.09	2.09	42.14
CANAL	0.5	0.78	1.1	2.32	1.6	7.28	8.28	6.75	6.51	6.82	0.47	2.6	45.01
WPB	0.27	1.03	0.96	4.21	0.71	5.6	13.36	8.59	10.13	13.91	0.17	4.26	63.2
BELLE	0.68	0.99	2.82	2.39	2.93	7.31	6.4	9.73	7.69	10.8	0.11	6.23	58.08
S41	0.82	0.54	1.67	2.13	1.13	3.17	6.4	7.09	4.52	8.45	0.56	4.81	41.29
S6	0.55	1.34	1.02	3.23	2.15	5.78	5.92	7.12	9.26	17.1	0.63	6.17	60.27
S39	0.48	1	2.08	4.21	5.5	3.9	8.53	8.1	5.16	11.29	0.11	7.05	57.41
G56	0.63	2.24	4.47	7.4	0.41	7.29	5.1	2.35	12.29	3.81	0.02	0.66	46.67
S7	0.78	0.94	4.3	3.94	0.28	4.25	12.88	3.98	3.82	6.88	0.07	0.88	43
S37B	1.2	0.51	3.15	7.16	2.21	5.27	7.08	5.34	7.18	3.79	0.1	0.24	43.23
S140	0.95	0.37	5.82	5.69	1.3	3.16	6.67	2.59	4.62	5.58	0.08	0.19	37.02
LAUD	0.95	1.44	5.28	2.9	3.12	6.08	6.75	6.09	5.59	11.6	0.7	4.39	54.89
S9	1.28	0.64	3.33	2.53	1.84	5.24	6.62	2.49	4.54	6.8	0.74	1.99	38.04
S29	1.04	0.56	9.71	3.96	1.3	3.29	8.31	2.1	4.7	6.64	0.36	0.42	42.39
MIA	1.02	0.68	3.91	3.06	2.26	4.68	4.63	4.71	7.83	8.82	1.38	1.48	44.46
S336	2.72	0.83	2.4	11.93	0.58	5.45	8.95	4.87	12.86	7.63	5.65	4.1	67.97
TAMI40	1.23	0.72	2.66	6.91	0.44	3.1	6.41	4.04	7.58	7.07	5.48	2.78	48.42
TAMIAIR	0.82	0.79	1.94	3.37	2.42	4.63	9.36	3.68	6.64	3.99	0.52	0.19	38.35
NP203	0.8	0.94	2.72	6.16	1.09	6.21	5.84	3.09	6.94	2.46	0.31	0.46	37.02
S331	0.71	0.46	2.61	3.75	0.12	7.38	5.8	6.87	7.33	2.58	0.32	1.84	39.77
HOMEFS	1.04	0.99	2.79	4.8	0.99	1.4	4.95	1.97	7.6	10.35	1.86	2.05	40.79
S20F	1.21	1.68	4.31	4.09	0.96	6.92	8.73	4.04	7.29	5.53	0.72	1.07	46.55
S18C	1.21	1.68	4.31	4.09	0.96	6.92	8.73	4.04	7.29	5.53	0.72	1.07	46.55